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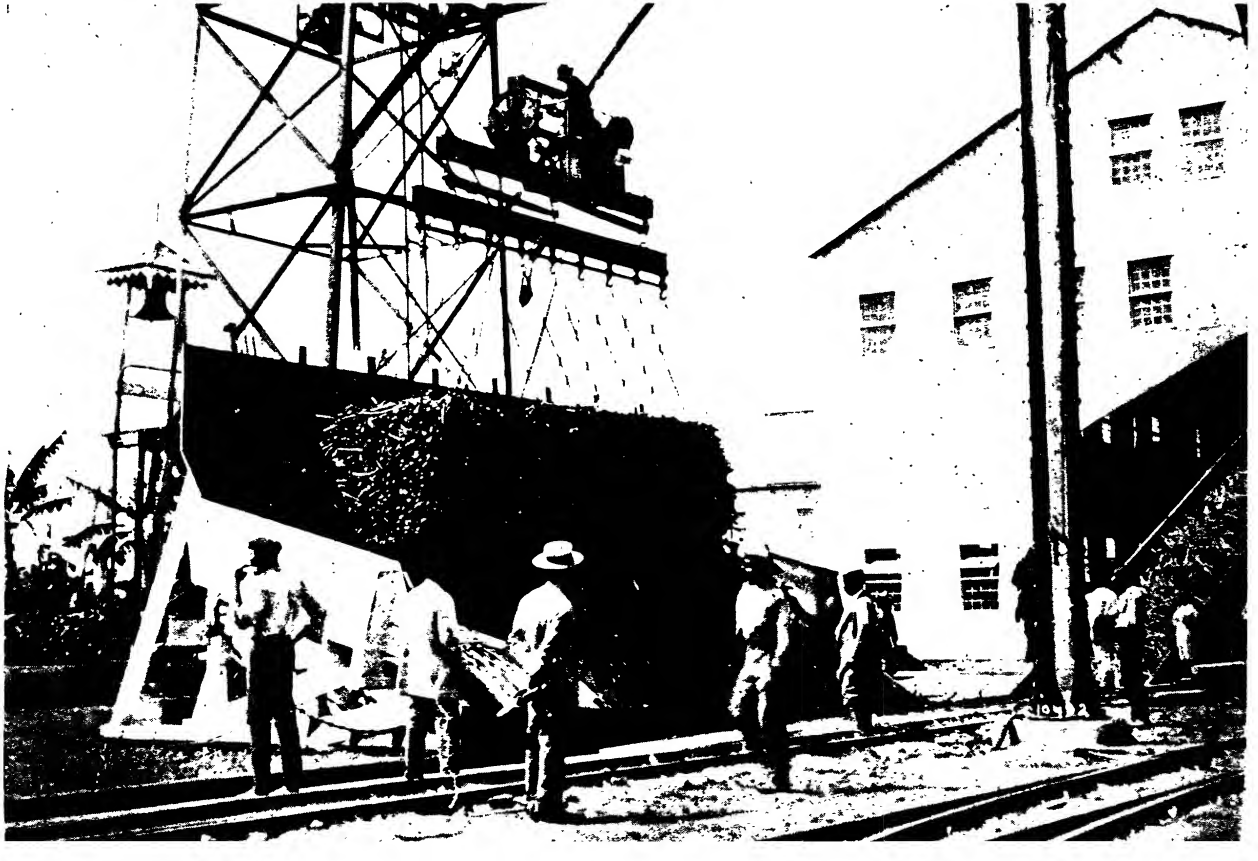

THE PRINCIPLES OF CANE SUGAR MANUFACTURE

(Together with a Description of the Machinery)

BY

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PREFACE

This book is written for the non-technical reader who possesses very little or no knowledge of cane sugar manufacture. The process of juice treatment is dealt with rather more fully than the machinery design, and in so doing it has been thought necessary to introduce certain simple chemical and technological ideas. The scope of the book is therefore limited to these requirements. A fuller and more technical discussion on cane sugar manufacture is to be found in the published literature and journals. The reader is referred to the following selection for his future use :—

"Cane Sugar." NOËL DEERR.

"Cane Sugar and its Manufacture." H. C. PRINSEN GEERLIGS.

"Machinery & Equipment of the Cane Sugar Factory." L. A. TROMP.

"Modern Milling of Sugar Cane." F. MAXWELL.

"Evaporation." A. L. WEBRE.

"Handbook of Sugar Analysis." C. A. BROWNE.

"Chemical Control in Cane Sugar Factories." Ass. Haw. Sugar Tech.

The International Sugar Journal. Monthly.

Facts about Sugar. Monthly.

Proceedings of the International and other Sugar Technologists' Associations.

Except for three chapters, the text is concerned with the process of manufacture and chemical control. It is based essentially on raw sugar practice and a separate chapter deals with the elaborations of the process necessary for the production of direct consumption sugars. This mode of procedure results in a more consolidated discussion and eliminates repetition.

I would wish to record herewith my very sincere appreciation of the generous assistance given to me by Dr. D. W. DUTHIE, Mr. J. C. MACAULAY and Mr. L. S. BIRKETT, who read and criticised parts of the manuscript in its earlier stages; and by Mr. J. P. OGILVIE, the Technical Editor of the *International Sugar Journal*, who read and commented on the whole manuscript at a later stage.

Finally, I must record my thanks to the Governing Body and to the Principal, Sir GEOFFREY EVANS, of this College for their permission to publish the manuscript.

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Introduction.

The sugar production of the world is nearly 30 million tons, of which 35 per cent. is derived from sugar beet and 65 per cent. from sugar cane. In open competition the beet industry could not at present place its sugar on the world markets at a cost as low as that of the cane industry. Sugar cane is therefore the cheapest source of sugar known to the scientific world.

Sugar cane is said to have originated in Asia. It gradually spread westwards, and Columbus introduced it to the West Indies. It is now to be found throughout the tropical world, although its commercial cultivation is limited to certain areas. Botanically, the sugar cane belongs to the family of grasses or "graminae." By scientific breeding many hundreds of different varieties have now been produced. When a variety is shown to possess desirable commercial properties, it is given an index letter and number, designating the experimental station of origin and the serial. Varieties with names are usually those which existed before breeding was known or carried out. The sugar cane plant grows in a clump like other grasses, but the individual stalks may be from $\frac{1}{2}$ in. to 2 in. in diameter and up to 14 ft. long, with five to fifty stalks per clump or stool.

The different varieties of sugar cane are characterized by their differences in habit, colouring, size and yield factors. A variety is a commercial success only when both the field and the factory properties are of high quality. Environmental conditions are of outstanding importance in their influence on these properties.

The number of sugar cane experiment stations in the world bears witness to the scientific activity which is taking place in an endeavour to increase yields and decrease costs. Almost every aspect of production is investigated; variety breeding, cultivation methods, manures and fertilizers, soils, together with

DIAGRAMMATIC FLOW SHEET OF THE PROCESS OF RAW CANE SUGAR MANUFACTURE

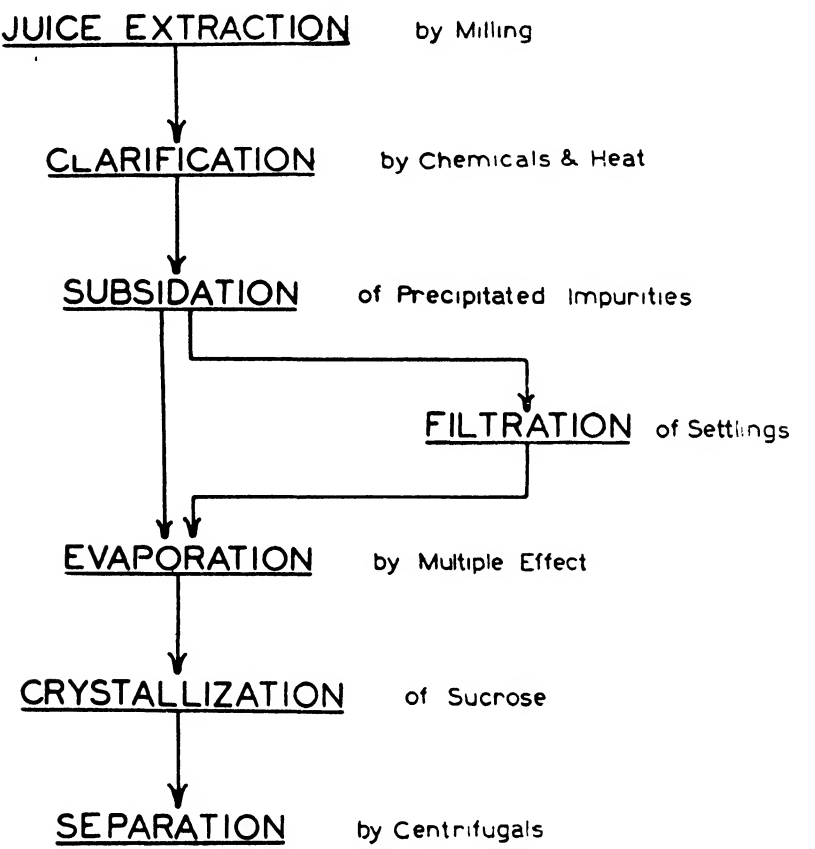


Fig. 1.

the engineering and technological work of the factory. Considering the quantity of sugar which is consumed annually, it is of interest to note that both as a food and as a chemical it is retailed in a purer state than almost any other product. Few laymen realize that the greater bulk of sugar which is bought is 99·9 per cent. chemically pure sucrose.

The cane crop is allowed 12 to 22 months in which to grow and ripen. Growth takes place during the rainy season chiefly, and as the rains begin to lessen, ripening sets in, during which time the sugar content increases. Yields vary with conditions up to 70 tons of cane per acre, although small isolated areas may show returns as high as 110 tons of cane per acre. The amount of sugar recovered from the cane depends on its sugar content and the efficiency of the factory to which it is sent. The ratio of tons of cane used to make 1 ton of sugar similarly depends on these factors, and 6 to 15 may be taken as the commercial extremes, with an average of 8 to 10.

The sugar factory does not make sucrose ; it merely recovers that manufactured in the plant by certain biological processes. The process of recovery consists essentially in extracting the juice, treating the extracted juice so that crystallization of sucrose is able to proceed successfully, and finally obtaining and separating the sucrose in crystal form. The steps are shown diagrammatically in Fig. 1.

The almost universal method of extracting the juice is carried out by squeezing the cane between a series of rollers under pressure (*Milling*). The extracted juice is then treated with chemicals—lime, sulphur dioxide, carbon dioxide or phosphate—and heat (*Clarification*). This treatment has the effect of precipitating certain of the impurities, which are then allowed to settle out (*Subsidation*). The clarified juice so obtained is decanted from the settlings, while they, in turn, are finally filtered (*Filtration*). The decanted clarified juice and the filtrate are next concentrated, the water being removed by evaporation in two stages. The first stage (*Multiple Effect Evaporation*) produces a syrup containing between 45 and 55 per cent. of sucrose. The second stage (*Crystallization*) continues the process but under more closely controlled conditions. It is at this point that the sugar first appears as very fine crystals, which are then built up to the size required for the final product. The crystals are then separated (*Separation*) from the residual juice or molasses in centrifugals, and finally weighed out into bags ready for shipment.

CHAPTER I.

Juice Extraction.

The cane, after cutting in the field, is loaded into mule, oxen or tractor-drawn carts, and either taken direct to the factory yard or else to the nearest railway loading station. On arrival at the factory, the cane is first weighed for control purposes (see Chapter XIII). The cart or truck is then unloaded on to a carrier which, in turn, delivers the cane to the mills for juice extraction. Fig. 2 is a diagrammatic flow sheet of the juice extraction process.

Unloading the Cane.

This operation may be carried out manually or mechanically. *Manual unloading* absorbs a large quantity of labour and can only be used when the tonnage to be handled per unit of time is comparatively small. It has one advantage, in that when properly controlled an even depth of cane can be maintained on the cane carrier, which leads to maximum mill efficiency.

There are several types of *mechanical unloaders*:—

The Overhead Travelling Crane.

This consists essentially of a pair of gantry girders or runways which support the travelling bridge. This bridge may or may not in turn support a similar but smaller travelling bridge or crab. The latter addition enables a load of cane to be picked up or dumped anywhere within the rectangle formed by the four corners of the gantry. It is evident that the gantry girders must extend at one end across the cane carrier and at the other end across the railway line. The cane is lifted out of the truck by slings or grabs and usually dumped on to a feed table from which it is fed to the carrier.

The Revolving Crane.

This may vary from a simple jib crane of the type used commonly for the loading of trucks in the field to the more

elaborate machine of the revolving derrick type. The performance of the former is obviously limited as compared to that of the latter, which, besides unloading, also provides ample storage

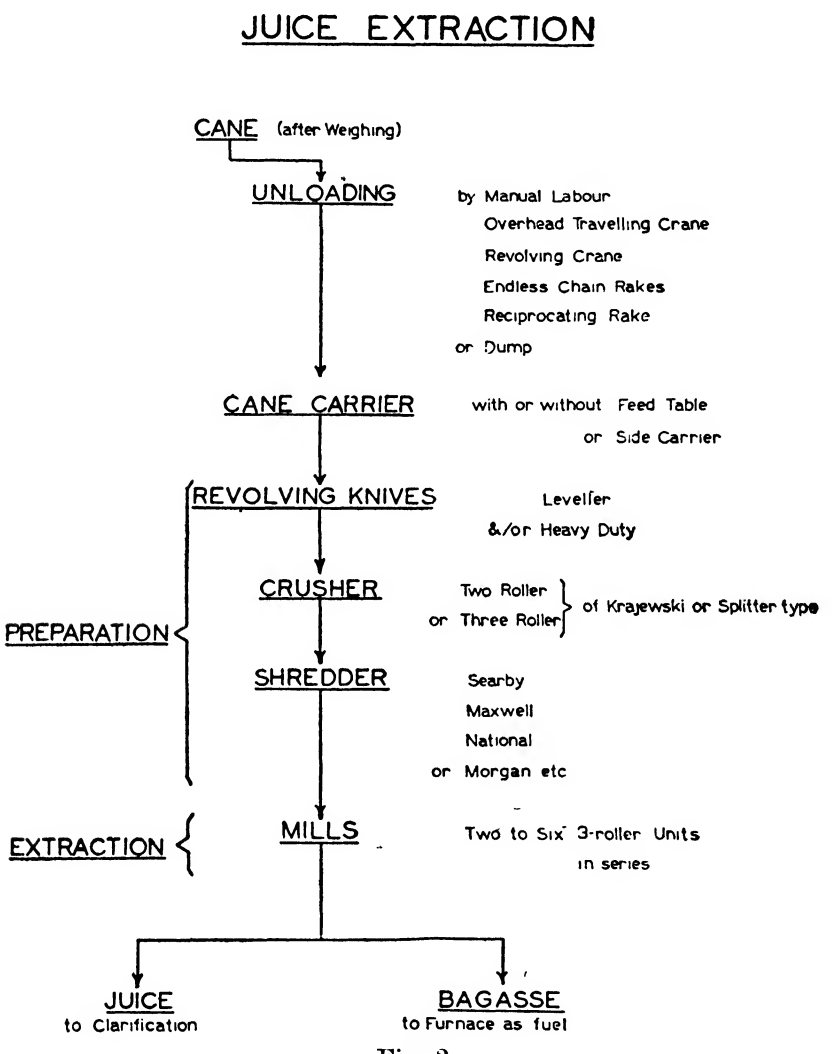


Fig. 2.

room. This feature is due essentially to the provision of a travelling trolley along the horizontal boom. In all types the mast is able to revolve round a complete circle.

The Endless Chain Rakes.

As the name implies, this device is essentially a series of chains to which prongs are attached. The chains rotate on chain

wheels attached to three shafts which form the corners of a triangular framework. One shaft acts as the pivot so that the framework can be raised or lowered by means of pulleys. The truck of cane is moved in under the raised frame and the chains are set in motion. As the frame is slowly lowered, so the prongs drag the cane from the truck into the carrier. The unloading is not absolutely complete and the canes left in the truck must be removed by hand.

The Reciprocating Rake.

This consists of a large, sturdy telescopic rake, attached to an eccentric device so as to produce a reciprocating motion. It drags the cane from the truck into the carrier. The rake is also pivoted to obtain a limited swing, so as to command the whole length of the truck.

The Dump.

The truck is run on to a length of railway line which forms the base of a cradle. It is then securely clamped to the cradle and tilted either sideways or endways by a hydraulic device or suitable gearing driven by an electric motor. The whole load is thereby dumped on to the carrier. The method is suitable for rapidly handling large tonnages of cane, and is in extensive use in Cuba.

The Cane Carrier.

The object of the cane carrier is to elevate the cane from the level of the mill yard to a height suitable for feeding into the mill.

The unloader may discharge the cane from the truck either on to the cane carrier direct or on to a *Feed Table* or *Side Carrier*. The object of either of these is to regulate the supply, so that the carrier is covered with as even a layer of cane as possible.

The *Feed Table* may consist simply of an inclined steel or wooden surface, from which the cane is fed to the carrier manually, or of a similar structure fitted with a mechanical feeding device. The *Side Carrier* is of similar structure to the cane carrier proper, except that the travelling apron is wholly horizontal. The advantage of a multiplicity of side carriers is that a number of railway trucks can be unloaded simultaneously.

Construction.—The Cane Carrier is composed of a wooden or steel framework and a travelling apron. The framework is so made that the apron is partly horizontal, for unloading or feed purposes, and partly inclined. Its purpose is to support the apron and the weight of the cane being fed to the mills. The sides of the framework above the apron are closed in so as to retain cane to a depth of 3 or 4 feet. The apron consists of two or more lengths of endless chain, to the links of which wooden or steel slats are bolted. The chains engage sprockets on a shaft which, in turn, are also supported by the framework, one set at the head and the other at the tail of the carrier. Intermediate support for the slats is provided. The slats may or may not be so designed as to overlap one with another. The purpose of this is to prevent pieces of cane becoming wedged between the slats and causing damage.

Method of Drive.—The travelling apron is driven through the sprockets at the head of the carrier by one of the following methods :—(1) Clutch ; (2) Donkey engine and gearing ; or (3) Electric motor and gearing.

When the carrier is driven by a *clutch*, the clutch transmits power initially derived from an engine driving one or more of the mill units. While clutch drive is simple, the objection is that the carrier must move at the set speed, since slipping the clutch is not always permissible. With the independent drive, such as is provided by the *Donkey Engine* or *Electric Motor*, the speed of the carrier can be regulated within limits to the requirements of the mill (see Milling Operating Efficiency).[1] For this purpose, the drive control is usually placed at the head of the carrier so that the operator can observe the condition of the feed to the first mill unit.

Milling.

Principles.

The sugar content of the cane is dissolved in the sap or juice. The juice is contained in millions of small fibre cells, each one of which must be ruptured for the juice to be expressed, hence modern methods of milling divide the process into two parts. Firstly, the cane is disintegrated and prepared so that

[1] Page 17.

as many as possible of the plant cells are ruptured. Secondly, the juice is extracted. The degree of preparation which the cane undergoes and the amount of juice extracted depend on the equipment installed and the efficiency of operation. Preparation is carried out by means of revolving knives, shredders of various designs and, to a lesser extent, crushers. Juice extraction is carried out by squeezing and the application of pressure on the mill rollers, together with the addition of maceration liquid. The more efficient the preparation, and the greater the degree and number of pressure applications, the less pure, comparatively speaking, will be the juice expressed. The reason for this is that cane may be divided into the hard, woody rind and the soft internal pith. Simple milling will extract the easily available juice in the pith. As more pressure is exerted so more of the less pure rind juice will be extracted.

Preparation.

Cane is inherently of tough construction, and a relatively large amount of power must be applied in its disintegration. The power used in preparation is virtually a re-distribution of the total power applied at the milling tandem. That is, an installation of knives using 60 h.p., for example, will not necessarily add 60 h.p. to the total power requirement of the mill. Preparation enables the mill to (*a*) extract more juice, and (*b*) work at higher capacity. The blanket or layer of bagasse is then in a better condition for feeding, that is the mill rollers can grip it more easily. The types of preparatory devices are :—

Revolving Knives.

These are usually installed across either the bottom or the top of the sloping part of the cane carrier.

Construction.—Revolving Knives consist of a horizontal shaft placed transversely across the carrier. The individual knife blades are attached to the shaft so that they revolve in a vertical plane. They vary in shape and method of attachment to the shaft and are enclosed by a metal hood.

Method of Drive.—One end of the shaft is either direct-coupled through a flexible coupling to a high speed steam engine or electric motor, or driven by means of a pulley and belt from a convenient engine. There must be plenty of power available

because the demands fluctuate over a wide range according to the depth and toughness of cane on the carrier. The average power requirement is about 2 h.p. per ton of cane ground per hour (2 H.P./T.C.H.).

Types of Knives.—There are two types : Levellers and Heavy Duty. The tips of *Leveller knives* are set further from the carrier slats than the tips of Heavy Duty knives. The essential purpose of the former is to level out the uneven tangled mass of cane on the carrier so that it can be more easily fed to the Crusher. *Heavy Duty knives* are set very close to the carrier slats, so that the mass of cane is cut through its entire depth. The action is very much more severe than that of Levellers and the power consumption is therefore greater. When both types are installed, the arrangement is that the cane passes first under the Leveller knives at the bottom of the carrier, then under the Heavy Duty knives at the head of the carrier, just before entering the Crusher.

Crushers.

A crusher consists either of one two-roller unit, of two or more such units in tandem, or of a three-roller unit. The function of the crusher is partly to assist in the preparation, but chiefly to extract as much of the readily available pith juice as possible (see Operating Efficiency).[1] It leaves the cane in a better condition for treatment in a shredder and for the repeated application of maceration liquid and pressure at the mills. A shredder is however not always installed.

Construction.—The two-roller crusher consists of two housings or headstocks which support the journals, one at each end of the roller shaft (see Three-roller Mill Unit Construction).[2] The housing is placed at an angle off the vertical so that, since the rollers are one above the other, the cane is able to fall from the head of the carrier to the opening between the rollers. The top roller has pressure exerted on it by means of springs, toggle gear or hydraulic rams (see Pressure Regulators).[3] The two rollers are held in place by means of the top cap which is, in turn, held down by means of the king bolts. The king bolts pass right through the housing from top to bottom and lend rigidity to the structure.

[1] Page 17. [2] Page 13. [3] Page 15.

Method of Drive.—One end of the bottom roller shaft is connected by means of a coupling to compound gearing (see Three-roller unit—Method of Drive).[1] The gearing is in turn driven by an engine or electric motor. When the crusher only is driven by the engine, some method of regulating its speed should be available for the operator working the cane carrier. The feed to the first mill is then under more direct control, and can be maintained at as even a depth of blanket as circumstances permit.

Types of Crushers.—There are two main types of crushers : Krajewski, and Splitter or Fulton. The names apply particularly to the type of groove on the roller surface. Other types are available but are less frequently seen. The *Krajewski* type grooving is made up of coarse zig-zag grooves across the face of the roller, those on the top roller intermeshing with the ones on the bottom roller. As the cane is fed through the crusher, part of the action is to cut it up into small pieces. The *Splitter* type is grooved with coarse circumferential grooves and with transverse grooves (see Grooving).[2] The coarse circumferential grooves produce the splitting action and the transverse grooves assist the feeding. Although there is no hard and fast rule governing the conditions under which one or other type is used, the Krajewski crusher is most frequently installed in factories noted for their high extraction and the Splitter crusher in those noted for their high capacity. The *Tandem crusher* was a development in Cuba during the War, when ever-increasing quantities of cane had to be dealt with during a period of rapid expansion. It is generally considered uneconomical except under such conditions. The *Three-roller crusher* is virtually an ordinary mill unit, the rollers of which are equipped with suitable grooving. The advantages of this type are that the cane does not have to be elevated to such a high level for feeding purposes, and that it receives two squeezes instead of one with only one extra roller.

Shredders.

Shredders perform their work of preparation in a somewhat drastic manner. Like revolving knives, they do not extract any appreciable quantities of juice from the cane. Most types,

[1] Page 14. [2] Page 15.

except the National in Queensland, are installed between the crusher and first mill unit.

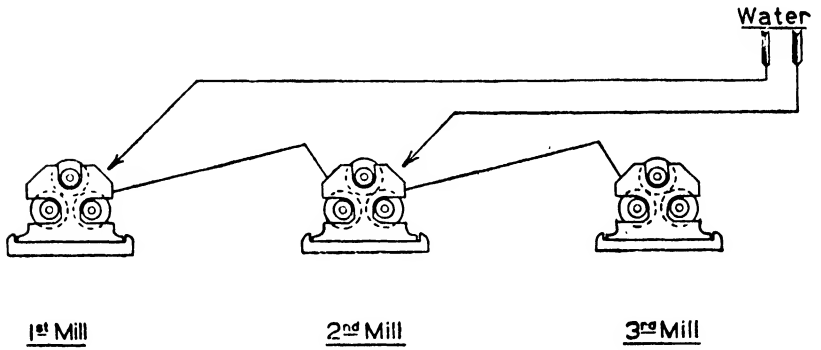
Construction.—Shredders are of varying designs. Almost every one uses a different principle to produce the ultimate effect. The *Searby* shredder consists of a series of vertical discs attached to and spaced along a horizontal shaft. A series of rectangular pieces of steel (hammers) are loosely slung between the discs so that when the shaft revolves, the hammers assume a radial position. The cane is passed between the tips of the revolving hammers and a set of horizontal stationary anvil bars. The effect is therefore one of repeatedly beating the incoming cane and so producing a pulverizing action. The *Maxwell* shredder is used in conjunction with the existing crusher. The essential part is a single shredder roller in which has been cut a series of transverse slot-shaped grooves. Three-edged teeth are fitted into the slots with spacers between them. The shredder-roller is held in position immediately behind the crusher rollers by means of brackets or a more elaborate arrangement. Its action is such that while the cane is still held by the crusher rollers, it is shredded by the teeth of the shredder roller, which revolves at high speed. The effect is therefore one of shredding in the true sense of the word. The *National* shredder, which is placed in front of the crusher in Queensland, consists of two composite rollers, the top one of which revolves at a different speed to the bottom one. As the cane is passed through, a shearing action is produced. The *Morgan* disintegrator is made up of a vertical disc mounted on a horizontal shaft. To the disc are attached a series of radially placed knives. It revolves within a casing fitted with a similar series of stationary knives. The chopped cane is fed to the centre of the revolving disc and centrifugal force throws the small pieces out to the periphery. In so doing, they must pass between the revolving knives and the fixed ones. The effect is one of intensive cutting.

Method of Drive.—The prime mover takes the form of a high speed steam engine or electric motor. The machine is driven either by direct-coupling, by belt, or by other suitable means. An important item to be considered is the power economy of the unit. The horse power required per ton of cane ground per hour varies widely with the different designs.

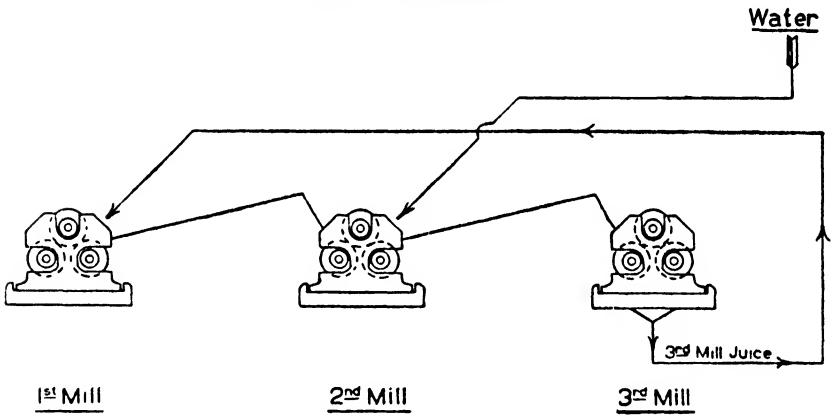
Extraction and Maceration.

Juice is extracted from the prepared cane by submitting it to a series of squeezes under high pressure. These squeezes are applied in a series of *three-roller mill units.* In each unit, the rollers are arranged at the corners of a triangle, so that the cane first passes between the top and one of the bottom rollers and then between the top and the other bottom roller. Two squeezes are therefore obtained in each unit. A milling tandem or train may be made up of two to six such units, the most common being either three or four. The cane is transferred from one unit to the next by means of an intermediate carrier. During its passage along the carrier, water or dilute juice from one of the later units is applied to it for maceration purposes. The *principle of maceration* is to steep the bagasse in a liquid which is more dilute as regards sugar than the residual juice in that bagasse. Hence the subsequent squeezes will bring about greater juice extraction. The more thoroughly the plant cells have been ruptured during preparation, the better will be the mixing of the maceration liquid with the residual juice, and hence the more efficient will be the extraction. In a milling train consisting of three units after the crusher or shredder, the general plan is to apply the juice from the third mill to the bagasse from the first and water to the bagasse from the second. This is known as *compound* maceration (see Fig. 3). When water is used at both points of application, it is known as *simple* maceration. Compound maceration is more economical on water. This is an important factor, because most of the water in the juice and that applied as maceration must eventually be removed by evaporation. The result is therefore a material saving in steam and hence fuel. The cost (in terms of fuel) of later removing the maceration water must be less than the extra sugar extracted, for the system to be economical. With modern steam generating methods, however, this factor need hardly be considered, but the cost of the extra equipment required to perform the water removal is an important point in determining the economical amount of maceration water to be applied. Similarly, the maceration liquid must be applied in such a way that it does useful work and the bagasse is thoroughly steeped. Besides the efficiency of cane preparation, the method of distribution of the

liquid on the bagasse plays its part. The ideal is to obtain an even sheet or spray of liquid, and to apply it at a point where it is able to penetrate the whole depth of the bagasse blanket.



SIMPLE MACERATION.



COMPOUND MACERATION.

Fig. 3.

Three-roller Mill Unit.

Construction.—A three-roller unit is made up of a horizontal *bed plate* resting on the foundations, which usually functions as a juice tray as well. Two vertical *headstocks* or *housings* which are bolted one on either side of the plate each support one end of the roller shafts. The shafts rest on bearings which are in turn supported in gaps in the housing. Each *roller* is made up of a steel shaft or gudgeon and a cast iron shell. The shell is either pressed or shrunk on to the shaft. It may or may not be held by keys, or it may be welded. The roller is therefore

made in two parts because the characteristics of two metals are required for the roller as a whole to function properly. The bearings, and therefore the rollers, are held in position in the gaps of the housings by means of caps. There are one *top cap* and two *side caps* to each housing. The top cap holds the top roller in its place and each side cap holds a bottom roller in position. The top cap is kept in place by means of two long bolts known as the *King bolts* which pass from the top of the housing to the bottom. Similarly, the two side caps are held in position by means of a pair of *side bolts* which pass from one side cap to the other. Each housing is therefore very securely trussed. The top cap is usually fitted with some method of applying pressure (see Pressure Regulators).[1] In order that the cane feeds continuously from the top and first bottom (or feed) roller to the top and second bottom (or discharge) roller, there is a narrow curved plate known as the *trash plate* placed between them. The trash plate is supported by a bar which is secured to the head-stocks or bed plate. The tip or toe of the trash plate bears on the feed roller and acts as a scraper plate. The top and discharge rollers are each fitted with a separate *scraper plate* to remove adhering bagasse.

Method of Drive.—Each of the bottom rollers is geared to the top roller by means of a pinion. The shaft of the top roller is coupled by a loose coupling to the shaft of the reduction gearing. The reduction gearing receives its motion from an electric motor or steam engine. A loose coupling is necessary so that the top roller can rise and fall freely under the influence of the pressure regulator according to the varying amounts of cane fed to the mill. The *reduction gearing* is usually of the compound type, that is, the reduction in rotative speed from the engine to the mill is accomplished in two or more stages. If simple gearing were used, the large size of the necessary gear wheel would be such as to offer difficulties in construction, transport, erection, etc. The speed of the engine must be geared down because the mill and the engine work efficiently at different speeds. Gearing is designed so that one engine can work one, two or three mill units, and it depends on a variety of factors as to which is used.

[1] Page 15.

Pressure Regulators.

On the old type of "solid" mill, there was no method of regulating the pressure exerted by the rollers on the incoming bagasse blanket. If the thickness of the feed was less than the opening between the two rollers, no pressure would be applied. Conversely, for each increase in thickness of feed over and above the roller opening, the pressure would become greater and greater. Finally a point could conceivably be reached when either a roller or housing would break. Pressure regulators therefore not only regulate the pressure applied to the bagasse but also act as safety devices. The commonest types are Springs and Hydraulic Rams. Toggle Gear is also used but less frequently. The regulators act on the bearings of the top roller, thus controlling and safeguarding all three rollers and the trash plate. *Springs* are compressed between two plates, the lower one of which bears on the roller bearing so that a predetermined pressure is obtained. The method is simple and effective. *Hydraulic Rams* are incorporated in the top cap and derive the pressure from an accumulator. The accumulator consists essentially of a plunger loaded with weights. The plunger works in a cylinder containing a fluid (castor oil, or soap solution) which transmits the pressure via steel piping to the rams. The pressure applied depends on the number of weights and the relative effective areas of the plunger and of the rams. It is initially created by means of a hand or steam pump. *Toggle Gear* is a spring device which produces slightly increasing pressure with increase in feed.

Grooving.

The surfaces of the shells of nearly all rollers are grooved. The fundamental idea of grooving is twofold : (*a*) to increase the gripping power of the surface, and (*b*) to facilitate juice drainage. There are certain patented types of grooves which are relatively uncommon. Usually, a combination of two or more of the following is the general practice :—

Circumferential V-grooves.—A groove of this type with an included angle of 60° will double the surface area of the roller shell. Normally included angles vary from 50° to 60°. The grooves are so cut that those on the top roller intermesh with those on the bottom rollers (see Fig. 4). When the grooves are

deep, a shearing action is produced because of the difference in surface speed of the ridge of one groove and the co-acting furrow

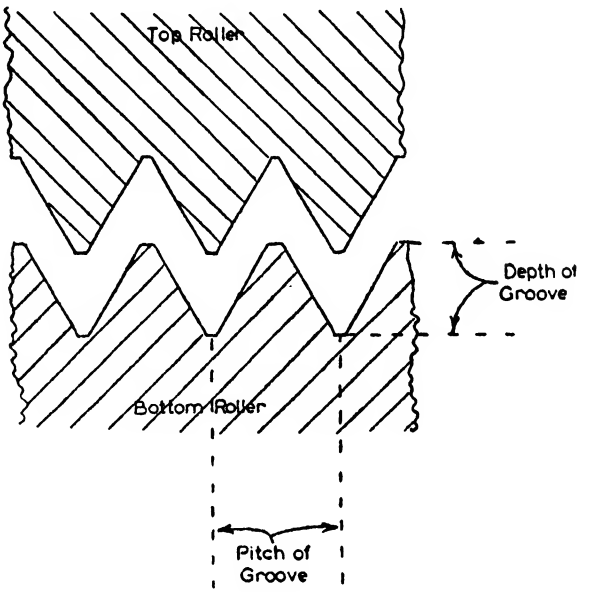


Fig. 4.—Circumferential V-Grooves.

of the other. The pitch, i.e. the distance between the ridges, and the depth vary and tend to decrease towards the later units of the mill tandem.

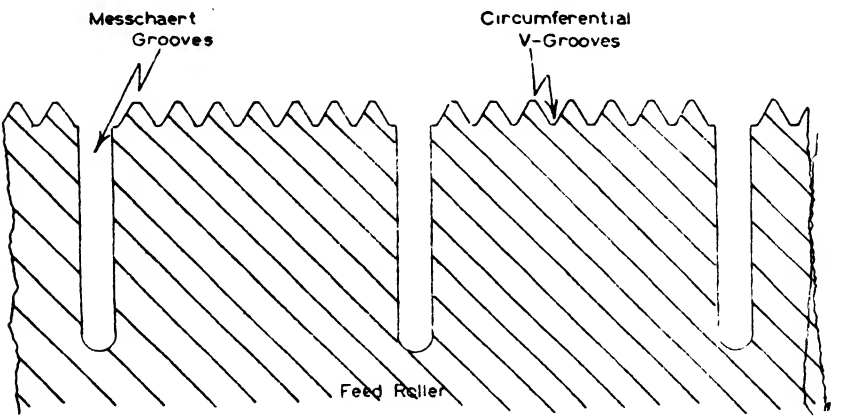


Fig. 5.—Messchaert Grooves on Feed Roller.

Transverse grooves of the Kay and Chevron types are cut across the face of the roller. The purpose is to increase the feeding

capacity. The Kay groove is square in cross section and during operation packs hard with bagasse. The Chevron groove is cut in such a manner that at the point of intersection with the circumferential V-groove a claw-like edge is formed, which drags the feed into the mill.

Messchaert grooves are deep circumferential grooves spaced about 2½ in. apart (see Fig. 5). Their sole purpose is to provide free drainage for the expressed juice when the bagasse is under pressure. Re-absorption is thereby reduced to a minimum and extraction is materially increased. Special scrapers must be fitted so that the grooves are kept free of bagasse.

Operating Efficiency.

The two important factors in mill operation are :

(*a*) Capacity ;

(*b*) Extraction.

The *capacity* of a mill is measured in terms of tons of material passed through per hour. The unit may be either tons of cane (T.C.H.) or tons of fibre (T.F.H.). The former is the more widely used, but the latter is the more correct technically, since it is the fibre or insoluble structural part of the cane which determines the amount of material able to pass through the mill openings in a given time. The *extraction* of a mill may be measured either in terms of sucrose extracted per cent. sucrose in cane, or in terms of normal juice lost per cent. fibre (see Control Reports).[1]

The factors which produce high capacity and those which produce high extraction act to a large extent in opposition to each other. For example, high capacity requires among other things wide mill openings and high roller speeds, while the reverse is true for high extraction. Such factors as a uniform feed of well-prepared cane are essential for both, and may therefore be termed a fundamental requirement for milling efficiency. One of the modern concepts of juice extraction by milling is an ample preparation of the cane, followed by the extraction of as much of the readily available juice as possible by the crusher, with subsequent maceration and squeezing in the mills. From the crusher onwards to the end of the mill, the process may be

[1] Page 139.

described as one of alternate heavy dilution of the residual juice and squeezing between the rollers under pressure. It is necessary therefore to provide means whereby ample water can be efficiently mixed with the bagasse (maceration device), to groove the surfaces of the rollers so that they take the feed (Circumferential V-groove, Kay groove, Chevron groove), to produce pressure so that the diluted juice is extracted (Pressure Regulators), and to provide means for the efficient drainage of the extracted juice (Messchaert groove). A limiting factor in the amount of maceration water added is the fact that capacity must be available at the evaporators for its subsequent removal.

The whole problem of mill operation is complex because of the vast number of possible variables. Some of these variables, such as mill openings, roller speeds, etc., can be controlled, while others change with differences, for example, in cane variety. It is for these reasons that milling results depend so much on the local experience and skill of the engineer. Similarly, without a knowledge of local conditions, it would be difficult except in general terms to forecast the capacity and extraction of any particular mill.

CHAPTER II.

Steam Generation.

Steam is generated by a fundamentally simple process. Fuel is burnt in a furnace and the heat created is transferred to water in a boiler. The efficiency with which this operation takes place depends not so much on the efficiency of design of the furnace and of the boiler individually, but on the degree of success with which the two are associated under operating conditions. The total heat made available by the combustion of the fuel is never recovered in the generated steam. Unavoidable losses occur. The task of the boiler operator is to reduce these losses to a minimum level. Steam is used in a sugar factory for the production of power and for heating and evaporating the juices and liquors. Hence the total available heat is limited by the available fuel, while the total required heat is dictated by the factory consumption. The maintenance of the two in equilibrium is governed by a complexity of operating factors. The available fuel in the cane sugar industry is the bagasse production of the mill. The steam requirement varies with the size, nature and lay-out of the factory. The rate at which fuel can be burnt is limited by the area of the grate, amount of air supplied for combustion and other factors. The rate at which steam is produced depends on the area of heating surface brought into contact with the hot gases, the temperature of the gases, the rate of fuel combustion, etc. No specific standards are available because of the variability of the many factors involved. Boiler designs are more stabilized than furnace designs, but it is a combination of the two which results in cheap steam.

Bagasse as a Fuel.

The cost of steam production plays a prominent part in the success of any industry. The cane sugar industry is fortunate in being able to materially reduce the cost of its steam by utilizing one of its waste products as fuel. The modern mill is capable under average conditions of producing bagasse with a moisture

content low enough for it to be burnt direct in the furnace. Bagasse, considered as a fuel, is of a different nature to coal, oil or any of the other common fuels. It burns with a long flame as opposed to coal which burns with a short flame. Another point of difference is the high moisture content of bagasse, about 44 to 52 per cent. This fact affects the fundamental principles of the design of the furnace, and special provisions have to be made to obtain complete combustion.

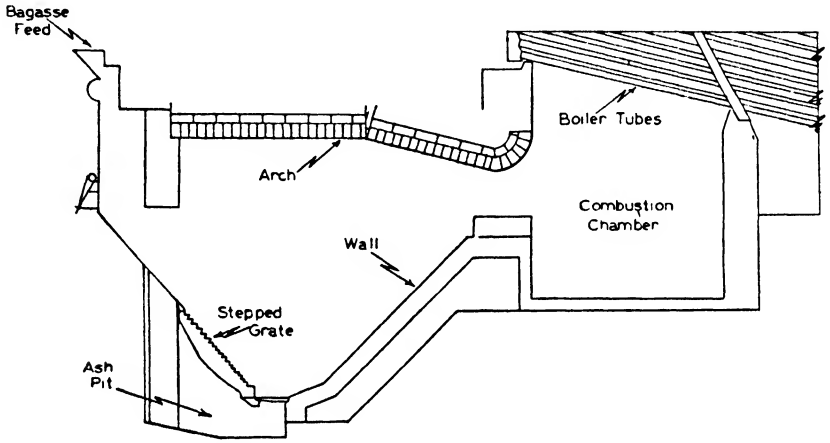


Fig. 6.—Main Features of a Typical Bagasse Furnace.

The Bagasse Furnace.

Features.

The important features of a bagasse furnace, such as is illustrated in Fig. 6, are set out as follows :—

(*a*) Arches are provided and placed in such a position that heat is radiated back on to the incoming bagasse so as to dry it.

(*b*) Walls are placed behind the grate so that the gases, in passing over them, are set into tumultuous whirl and are thoroughly mixed.

(*c*) Ample volume is provided in the combustion chamber between the grate and the boiler, so that complete combustion is ensured before the gases start to impart their heat to the water in the boiler.

The bagasse from the mills enters the furnace and falls on to the grate. The zones of drying, carbonizing and burning the fuel supply slowly merge into each other. The evaporated

moisture, under furnace conditions, is changed into steam, which mixes with the other products of combustion, the gases. The gases pass over the wall and combustion is completed in the combustion chamber. They then impart their heat to the water in the boiler, emerge into the main flue and are discharged up the stack.

Grates.

Grates are of two main types :

(*a*) Stepped ;

(*b*) Flat.

A *stepped* grate is, as its name implies, very much like the front of a steel step ladder. Bagasse is fed to the top and it slowly descends under its own weight, until at the bottom it is completely burnt. Each step of the grate is made up of a series of bars which fit into slots and are removable. *Flat* grates are of various shapes, and are also made up of a series of bars. Bagasse is fed from above so that a cone-shaped heap is formed. Drying takes place at the top of the cone, and the bagasse slowly descends into the zone of combustion at the bottom of the cone.

Draught.

In order that complete combustion can take place, it is necessary that the fuel should be supplied with the requisite amount of air. Air contains approximately one-fifth of its volume as oxygen. Oxygen is the gas which is active during combustion in the furnace. Hence for each unit volume of oxygen required for the combustion of the fuel five times that unit volume of air must be supplied to the grate. Under working conditions, excess air is admitted so as to ensure complete combustion. Air is supplied to the furnace by virtue of the draught. *Furnace draught* is of three kinds :

(*a*) Natural draught ;

(*b*) Induced draught ;

(*c*) Forced draught.

Natural draught is draught set up by the prevailing wind and by the current produced as the hot flue gases ascend the stack. These conditions therefore limit the amount of air which can be supplied to the furnace.

Induced draught is produced when a fan is placed at the bottom of the stack and air is drawn through the furnace. Under these conditions the air pressure in the furnace is less than that of the atmosphere.

Forced draught implies the use of a fan which blows air on to the grate through a series of ducts or *tuyères*. The pressure in the furnace is then slightly greater than that of the atmosphere.

The amount of air admitted to the furnace can be easily controlled in the last two methods, by varying the speed of the fan. With natural draught the only control is by means of the flue dampers. It is important that the air supply should fit requirements, because too little air results in incomplete combustion and too much air will blow holes in the fuel layer on the grate.

It is self-evident that admission into the furnace of the large quantities of cold air required for combustion will tend to reduce the furnace temperature. In some boiler plants this is obviated by the use of an air *pre-heater*, which heats the air prior to admission on to the grate. The source of heat is usually the waste flue gases, in which case the pre-heater is placed between the boiler and the stack. Forced draught is used to blow the air through the pre-heater on to the grate, and induced draught is used to draw the air from the grate through the furnace. Such an arrangement is known as *balanced draught.*

The Boiler.

Boilers are of two main types :

Fire tube ;
Water tube.

Fire Tube Boiler.

This consists of a large cylindrical drum with a series of tubes passing from one end to the other. The water is contained in the drum, and hence is in contact with the outside of the tubes. The furnace gases pass through the inside of the tubes. The area of shell and tubes which is in contact with both the water and the furnace gases is known as the *Heating Surface.* It is measured in square feet. In the *return tubular boiler*, the

gases from the grate pass along the under side of the horizontal drum, then up and back through the inside of the tubes. Fire tube boilers are characterized by their slow raising of steam, low rate of steam production and low operating steam pressures. There are several variations of design, but the type is gradually becoming obsolete for sugar factory work.

Water Tube Boiler.

The water tube boiler comprises one or more cylindrical drums with an arrangement of tubes which varies with design. In all cases, the tubes are filled with water and are so placed that a definite path of circulation is set up. This feature, together with the large number of tubes which can be used to provide heating surface, results in rapid steam production. Also the principle of design is such that boilers of this type can be made to carry high pressures with absolute safety. The path of the gases over the tubes is arranged in a series of passages or passes, so that more efficient heating is obtained.

Boiler Accessories.

During operation, boiler feed water is pumped into the boiler at approximately the same rate as steam is withdrawn for use. The *boiler feed water pump* must of necessity be of an absolutely reliable type, since there is an optimum level of water to be maintained in the boiler for proper working. The level of water in the boiler is seen by inspection of the *gauge glass*. Too high or too low a level is signalled to the operator by means of a *water level alarm*. The dangers of too low a level are self-evident. Too high a level may result in water being syphoned over into the steam pipes by the flow of steam. It is known as *priming*. Priming may also occur if the water is impure or the boiler improperly designed. The pressure of the generated steam is controlled by a safety device. Any steam over and above the required pressure is released through the *safety valve*, which may be of varying design. The pressure of the steam in the boiler is indicated by the *pressure gauge*. The steam is drawn off from the boiler drum through a valve which connects to the steam main to the factory. At the lowest point in the boiler, there is a *mud drum* in which the impurities from the feed water collect. They are ejected periodically by opening the *blow-down valve*.

Boiler Feed Water.

The boiler feed water should be the purest water available. The greater part of the heat generated in a sugar factory is used for heating or evaporation. The condensed steam or condensate therefore forms a liberal source of hot water supply for this purpose. It is relatively pure, provided no contamination has taken place. Water from other sources of supply may have to be used as make-up. It is in the interests of economy to have such water tested and a treatment specified to prevent *boiler scale* formation.

By continuous evaporation any impurities present in the water are forced out of solution and deposited in the form of a scale or incrustation on the inside of the heating surface. Certain chemical preparations may be added to the feed water, so that the impurities form a sludge or mud instead of a scale. The sludge collects in the mud drum and is ejected as described. The prevention of boiler scale is one of the most important factors in boiler operation, because its presence results in excessive fuel consumption and introduces an element of risk of explosion.

Economizers.

In order to reduce the amount of heat used by the boiler in heating the feed water up to boiler temperature, a device known as a *Feed Water Heater or Economizer* may be added. Waste heat, such as flue gases, is used. Such equipment is placed between the boiler feed pump and the boiler.

Steam.

The generation of steam is basically an exchange of heat from the hot furnace gases to the water in the boiler.

The temperature at which water boils varies with the prevailing pressure. Cold water at 84°F. on being pumped into a boiler must first be heated to the boiler temperature. The heat required to do this is known as the *Sensible Heat.* Further heat is then added to change it into steam. The heat required to do this is known as the *Latent Heat.* During this period of heat absorption there is no rise or fall in temperature. Steam therefore contains Sensible + Latent Heat. The unit of heat is called

a *British Thermal Unit* (*B.T.U.*). It is defined as the amount of heat required to raise the temperature of one pound of water through one degree on the Fahrenheit scale. Hence, if the initial temperature of a pound of water (84°F.) and the temperature in the boiler to which the water must be heated (at 150 lbs./sq. in.

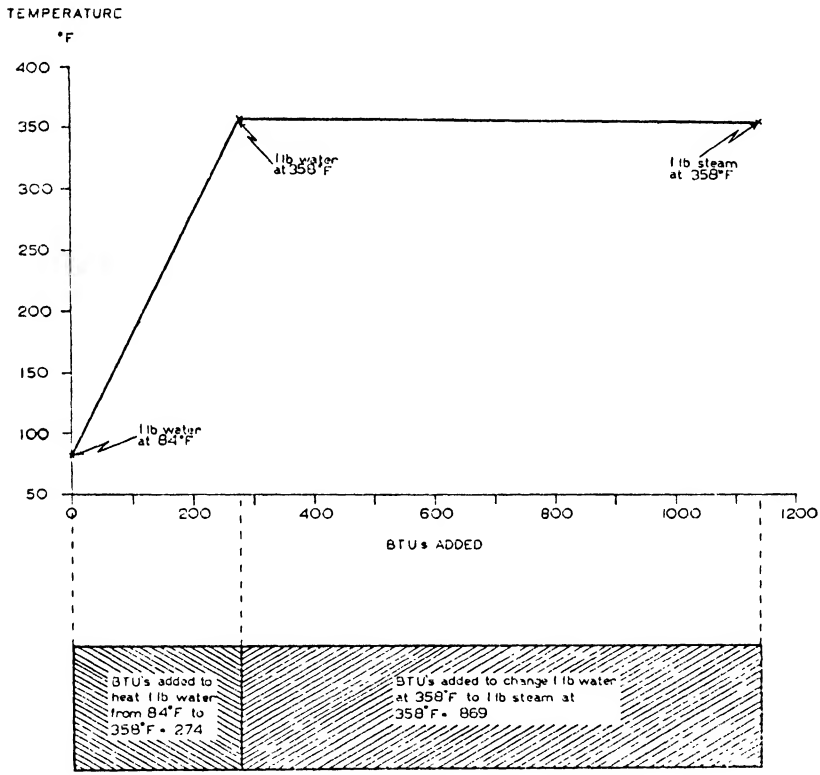


Fig. 7.

this temperature is 358°F.) are known (see Fig. 7), the amount of sensible heat required can be calculated thus :

358 — 84 = 274°F. through which the water must be heated.

By definition, this requires 274 B.T.U.

To change the pound of water into steam, the latent heat must now be added. This also varies with the pressure and the temperature as shown in Table I (page 26).

TABLE I.

	Pressure lbs./sq. in.	Boiling Point of water °F.	Latent Heat B.T.U.
Atmospheric Pressure	0	212	971
	50	281	926
	100	328	893
	150	358	869
	200	382	850

In order to change 1 lb. of water at 358°F. into steam at that temperature, the amount of heat required will therefore be 869 B.T.U. The total heat added to the lb. of water at 84°F. to produce steam at 150 lbs./sq. in. is therefore :—

$$274 \text{ B.T.U.} + 869 \text{ B.T.U.} = 1143 \text{ B.T.U.}$$

It is noticeable that of the total heat (1143 B.T.U.) added, $\frac{869}{1143}$ or approximately three-quarters of it is required to change the heated water into steam. This fact is of value in using steam to heat or evaporate juice, because by making suitable arrangements so that the steam will condense back to hot water about three-quarters of its heat is utilized without any alteration in temperature.

When the whole of 1 lb. of hot water is changed into steam at the same temperature, it is known as *Dry or Saturated Steam.* A small portion of it may condense into small droplets of water at the same temperature, which remain suspended in the steam. It is then known as *Wet Steam.* Further heat may be added to dry steam so that while there is a rise in temperature there is no change in pressure. It is then known as *Superheated Steam.* The advantage of superheated steam is that since steam loses heat in the pipe-line between the boiler and the steam engine in keeping the steam pipe hot, the heat lost will be part of the superheat so that the engine is provided with partially superheated steam or perhaps dry steam and no moisture is admitted to the cylinder.

The steam pressure most commonly used in sugar factories is in the neighbourhood of 160 lbs./sq. in. Factory equipment requiring steam at a lower pressure than this is fed from a *reducing valve.* A reducing valve automatically maintains a lower pressure in a subsidiary steam line as long as it is fed with steam at a higher pressure from the main steam line.

Steam is used in the factory to operate the engines and pumps and to carry out the processes of heating, evaporation and crystallization. A large proportion of the heat required for the last three processes is economically obtained from the exhaust steam of the engines, which is discharged into the *Exhaust Steam line or Back Pressure line.* This conveys the steam to the heaters, evaporators, etc., for consumption. The pressure in the exhaust steam line is generally of the order of 5 to 8 lbs. /sq. in. When more exhaust steam is produced than can be utilized, the surplus must be released to the atmosphere. Such a procedure is a waste of heat, and the practice should be eliminated by a careful study of the heat economy of the factory.

In order to conserve heat, all steam pipes, either live or exhaust, are covered with a heat insulator such as magnesia or asbestos. Such a covering is known as *Lagging.* The cylinders of steam engines, heaters and evaporator vessels are similarly covered ; the lagging may or may not be enclosed by wooden slats. The loss of heat by radiation from even well-lagged pipes is an appreciable quantity. Since the heat supply is limited, lagging is an economical expenditure.

Steam Economy.

The steam consuming units of a sugar factory may be classified as follows :—

(*a*) Power—mill engines, juice pumps, vacuum pumps, generators, etc.
(*b*) Heating.
(*c*) Evaporation.
(*d*) Crystallization.
(*e*) Radiation losses.

The *economy* with which steam is produced depends on the moisture content of the bagasse, the fibre content of the cane, and the efficiency of the design and operation of the boiler plant. The ideal balance is one in which the factory operations consume the same amount of steam as the boiler produces with bagasse as the sole fuel. Actually, in practice, the maintenance of a small surplus of bagasse is advisable to cover the periods when the mill is not working but some of the other factory units are.

Bagasse economy can, under certain conditions, be practised to the extent of the surplus bagasse becoming a financial loss. When large amounts are saved, it must be baled to reduce the bulky volume, transported and dumped at convenient points. The reverse of such a situation is expenditure on wood, bamboo or oil to make up the deficiencies of the bagasse supply.

It is fundamentally necessary for the furnaces to be of an approved design and efficiently operated, although this is not always the case. The moisture content of bagasse is a heat expense because some of the heat which should be generating steam is being used to evaporate fuel moisture. It should, therefore, be maintained at as low a figure as possible. The fibre content of cane directly controls the amount of bagasse which is produced, and therefore the extent of the fuel supply. With modern equipment, a heat balance can be obtained even with low fibre contents, but the necessary plant is of course extensive and expensive.

Appreciable steam economies may be brought about by the elimination of all small steam consuming units, such as pumps, and their replacement by electrical units, by reducing the lengths of all steam pipes as much as possible, by maintaining juice temperatures as high as practicable (e.g. the juice supply to the evaporator), by repairing leaking valves, glands, etc., and by strict attention to boiler and furnace operation.

CHAPTER III.

Screening and Clarification.

After extraction by the mills, the juice is passed through a metal screen to remove suspended material. It is then weighed or measured for control purposes (see Chapter XIII). Next, chemicals and heat are added to it in order to remove certain of the impurities. This step is necessary before the subsequent processes of evaporation and crystallization take place. The thoroughness with which the clarification treatment is carried out depends on the inherent qualities of the juice and the type of sugar to be manufactured. The quality of the juice from the clarification point of view depends on :

(*a*) Environmental and climatic conditions during the growth of the cane ;
(*b*) The variety of cane being treated ; and
(*c*) The degree of extraction accomplished by the mill.

Differences in juice quality are shown by differences in analyses.

Each one of the different sugar types manufactured demands a different treatment for its production. Types of sugar may be divided into :

1. *Raw Sugar, 96° Test Sugar or Grey Crystals*, which is almost exclusively shipped to refiners in America, Canada or Europe.

2. *Direct Consumption Sugars* which are sold and consumed as made by the cane sugar factory. These may be again sub-divided into :

(*a*) West Indian Crystallized, Demerara Crystals or Yellow Crystals ;
(*b*) Sulphitation White sugars ;
(*c*) Carbonatation White sugars.

Of these different types, by far the greater proportion of cane sugar is made in the country of origin as Raw 96° Test sugar. Its method of production may be considered as the basis of the other methods in which certain steps in the processes are the same and others an elaboration. The manufacture of Raw Sugar is therefore first described fully to the ultimate point of bagging. The differences in the production of the other types are then described separately.

Screening.

This operation is carried out near the mill so that the removed material, consisting of pieces of bagasse and of bagacillo,[1] can be readily returned to an intermediate carrier[2] for subsequent extraction of the juice therefrom. The screen may consist either of a perforated copper or brass sheet placed over the juice tank or of a more elaborate construction, such as one of the rotary or vibrating devices. In the former type, the surface of the screen is maintained free of bagacillo by means of scrapers which also elevate it to a point suitable for distribution to the intermediate carrier. In the latter type, the screen is made in the form of a drum which revolves, and it is situated over the intermediate carrier. The unstrained juice is delivered to it by means of a special type of *Unchokeable Pump*, and is discharged over the inside or outside of the revolving screen. The separated screenings are removed from the drum face, and the screened juice is collected in a suitable trough. Another design takes the form of a vibrating framework to which the screen is attached, so that a sieving action is produced. Such a device is placed over the juice tank.

Clarification.

The mechanism of clarification is of an intricate nature. It is difficult to appreciate fully the reactions which take place within the juice upon the simple addition of lime and heat. Prior to giving a description of the clarification process used for the production of raw sugar, a general discussion is appended in which the juice constituents themselves are first examined, and then certain fundamental ideas of clarification are outlined.

[1] Small pieces of bagasse, bagasse flour. [2] Page 12.

The Constituents of Cane Juice.

The constituents of cane juice, together with the approximate quantities present, are as follows :

Water	77 to 88%	
Sucrose	8 to 21%	12 to 23% Total Solids or degrees on the Brix Hydrometer. (See Chapter XIII).
Reducing Sugars	0·3 to 3·0%	
Other Organic Compounds	0·5 to 1·0%	
Inorganic Compounds	0·2 to 0·6%	

"Other Organic Compounds" include proteins, organic acids, pentosans and pectins (gums), colouring matters and wax. The "Inorganic Compounds" are made up of the phosphates, chlorides, sulphates, nitrates and silicates of sodium, potassium, calcium, magnesium, aluminium and iron chiefly.

Cane juice is acid in reaction. This acidity can be neutralized or destroyed by the addition of an alkali such as caustic soda solution or lime suspension. The degree of acidity is measured in terms of *Hydrogen-ion Concentration* by a logarithmic scale known as *pH*. When common salt (NaCl) is dissolved in water, some of the NaCl molecules split up into electrically charged Na and Cl atoms (Ions). This splitting is known as *Ionization*, and the electrically charged particles are called Na-ions and Cl-ions. Similarly, water (H_2O or HOH) ionizes into H-ions and OH-ions, and when the number of each of these is exactly the same, that is :

H-ion concentration = OH-ion concentration,

the water is then electrically neutral. The addition of an acid, for example sulphuric acid (H_2SO_4 which ionizes into H-ions and SO_4-ions), to such a water upsets this balance and there are then more H-ions present than OH-ions. Similarly, the addition of an alkali, for example lime ($Ca(OH)_2$, which ionizes into Ca-ions and OH-ions) will also upset the balance and there will then be less H-ions present than OH-ions. The number of H-ions in a sample of pure water can be determined, and it is the reference point for the whole *pH* scale. Pure water is *pH* 7·00 (Neutral Point) ; an acid has a *pH* less than 7·00 and an alkali a *pH* more than 7·00. Since the scale is logarithmic, a *pH* value of 5·00 indicates an acid ten times as intense as one having a *pH* value of 6·00.

The *pH* of raw cane juice varies from *pH* 4·80 to *pH* 5·60.

The turbidity of cane juice is due to the presence of *colloids*. A substance is said to be a colloid when it exists in solution in a permanent state of fine dispersion. The particles of such a dispersion are larger than molecules but smaller than the finest suspension. As opposed to a suspension, a colloidal solution is stable and will not settle. Settling takes place only when the conditions are altered so that flocculation, or coagulation, takes place. The conditions required for flocculation include, amongst others, the addition of heat or the addition of solutions of chemicals (electrolytes). Some colloids are flocculated fairly readily while others do so only with the greatest difficulty. There is a characteristic hydrogen-ion concentration for each colloid at which flocculation occurs most easily. It is known as the *Isoelectric Point* of the colloid. By passing an electric current through a colloidal solution, the particles may, under certain conditions of illumination and magnification, be observed to migrate towards the oppositely charged pole. Cane juice colloids are charged electro-negatively and would therefore migrate towards the positive pole of such an apparatus. They consist chiefly of protein, pentosan, pectins, wax and some inorganic compounds (chiefly silica).

When a solution containing *sucrose* is heated, or when acid is added to it, a chemical reaction known as hydrolysis (inversion, decomposition or destruction) takes place whereby the sucrose is changed into *reducing sugars* (invert sugar, glucose). *Reducing sugars* are not crystallizable and therefore play no part in the commercial value of sugar cane juice, except in so far as their presence affects the recovery of sucrose. An excessive addition of lime to the heated juice produces a characteristic reddish-brown colour, due to some of the lime combining with the reducing sugars, forming decomposition products. These are hygroscopic in nature and impart to the final sugar their colour and a sticky appearance. Certain of the other *organic and inorganic compounds* of cane juice form insoluble compounds during the clarification treatment and hence are precipitated and removed in the settled mud. Others persist the whole way through the manufacturing process and are found in

the final molasses. The degree of precipitation obtained depends on the manner in which clarification is carried out, and this in turn depends to a large extent on the type of sugar to be manufactured.

The Mechanism of Clarification.

Clarification processes vary in their intensity, that is, they vary in the amounts and kinds of chemicals added to the juice. Also, there is a further variation in the degree and time of heating. The basic idea of all processes is to obtain (*a*) coagulation of the colloids, and (*b*) formation of an insoluble precipitate, so that the juice is left clear, bright and of suitable colour and *pH* value. Whatever other chemicals may be used as well, the addition of a suspension of lime (hydrated lime or calcium hydroxide) forms the basis of nearly all commercial clarification processes. This, together, with heat, has the following effects on the juice :

(1) Change in hydrogen-ion concentration, i.e., a rise in *pH* value due to the addition of OH-ions.[1]
(2) Coagulation of some of the colloids due to this change in hydrogen-ion concentration and to the rise in temperature on heating.
(3) The formation of insoluble calcium compounds.
(4) The formation of soluble calcium compounds and other reaction products.

Rise in pH Value.

A rise in *pH* value is essential, because raw cane juice is acid in reaction. If it were passed through the factory in this condition, sucrose would be lost by inversion, as previously explained.[2] The effect could equally well be brought about by the addition of caustic soda or some other alkaline substance. Factors in favour of the use of lime are cheapness and the fact that it forms insoluble calcium compounds, the significance of which will be seen later.

Coagulation of Colloids.

Only the more easily coagulated colloids are precipitated. Extremely expensive and extensive treatment would have to be carried out to rid the juice of all its colloids, and even then success would be uncertain. What coagulation does take place

[1] Page 31. [2] Page 32.

is due both to the rise in *pH* value and the formation of calcium complexes, and to the rise in temperature. Their separate effects can, however, easily be demonstrated by simple experiments.

Formation of Insoluble Calcium Compounds.

Juice contains certain chemical substances which form insoluble compounds with lime and heat. Chief amongst these is *phosphoric acid*, which forms insoluble calcium phosphate. The presence of an adequate phosphate precipitate is essential for good raw sugar clarification, since it is conceived that this precipitate enmeshes or entrains the coagulated colloids, and on settling carries them to the bottom of the tank. In modern practice, this action is thought to be of such importance that the phosphate content of the juice is periodically determined, and any deficiencies made up by the addition to the juice of phosphoric acid in a suitable form. An important factor in this concept is that the precipitate should be formed within the juice so that the entrainment of colloids takes place coincidently with the formation of the precipitate. Exactly the same idea is present when sulphur dioxide or carbon dioxide is added to the juice. In such cases, relatively immense quantities of calcium sulphite or calcium carbonate are formed and the entrainment and cleaning action is therefore very much more thorough.

Formation of Soluble Calcium Compounds.

The formation of soluble calcium compounds results in unwanted substances being dissolved in the juice. It is however a necessary evil and cannot be avoided because of the very nature of cane juice constituents. When excessive amounts of lime are added, the reducing sugars react to form reddish-brown compounds, as already explained.[1] Even under carefully controlled conditions, part of the added lime will go into solution in combination with the organic acids, which results in a rise in the calcium content of the juice. This has an ultimate effect on the amount of sugar recovered, and the lime addition should therefore be controlled as closely as possible.

ALTERNATIVE RAW SUGAR CLARIFICATION PROCESSES.

The clarification process used for the production of raw sugar is of a comparatively simple nature. It consists of the simple

[1] Page 32.

addition to the juice of milk-of-lime, and perhaps phosphoric acid, and heat. A notable exception is Natal, in which a more severe treatment is necessary due to the inherent qualities of the juice. There are variations, however, in the order in which liming and heating are carried out. They are illustrated in Fig. 8 and described herewith :

Cold Liming.

Milk-of-lime is added to the raw juice to bring about a reaction of *pH* 7·8 to *pH* 8·4. The actual amount added depends on the particular juice, the ultimate aim being to obtain a clarified or settled juice of *pH* 7·0 to 7·2. After liming, the juice is then heated to 212° to 215°F. and settled in subsiders. This process gives satisfactory results with easily clarifying juices, but phosphoric acid paste diluted to 10°Bé. may have to be added prior to the addition of lime, should the natural phosphate content of the juice be less than 0·025 to 0·030 grms. P_2O_5 per 100 ml. juice. When phosphoric acid is added, it must be remembered that the volume of settlings (muds) will be increased, and that the rate of filtration of the muds in the filter-presses will be slower.

High Liming and Phosphating back.

In this variation of the cold liming process, the juice is limed initially to *pH* 9·0 to *pH* 10·0, after which 10°Bé. phosphoric acid is added to reduce the reaction to *pH* 7·6. The juice is then heated to 212° to 215°F. and settled. The reaction of *pH* 7·6 will, on average juices, give a clarified juice of the desired *pH* 7·0 to 7·2, but it may need adjustment in certain instances. This process gives satisfactory results on a wider range of juice types than cold liming, but the great disadvantage is the larger volume of settlings.

Hot Liming.

The raw juice is heated to 212° to 215°F. Milk-of-lime is then added to the hot juice to a reaction of *pH* 7·8. After settling, the desired reaction of *pH* 7·0 to 7·2 should be obtained. The theory underlying this process is that by heating the raw juice (*pH* 4·8 to *pH* 5·6) first in acid solution, certain of the colloids are coagulated without the addition of milk-of-lime, because that reaction is near the isoelectric point. The addition

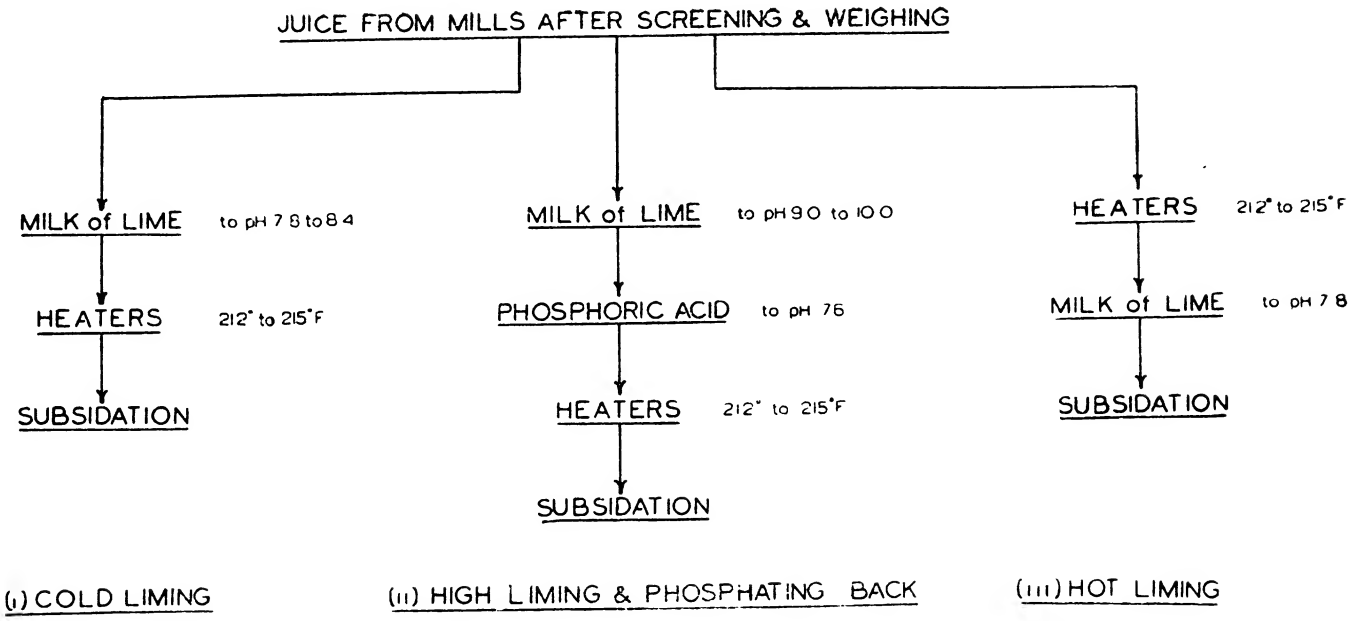
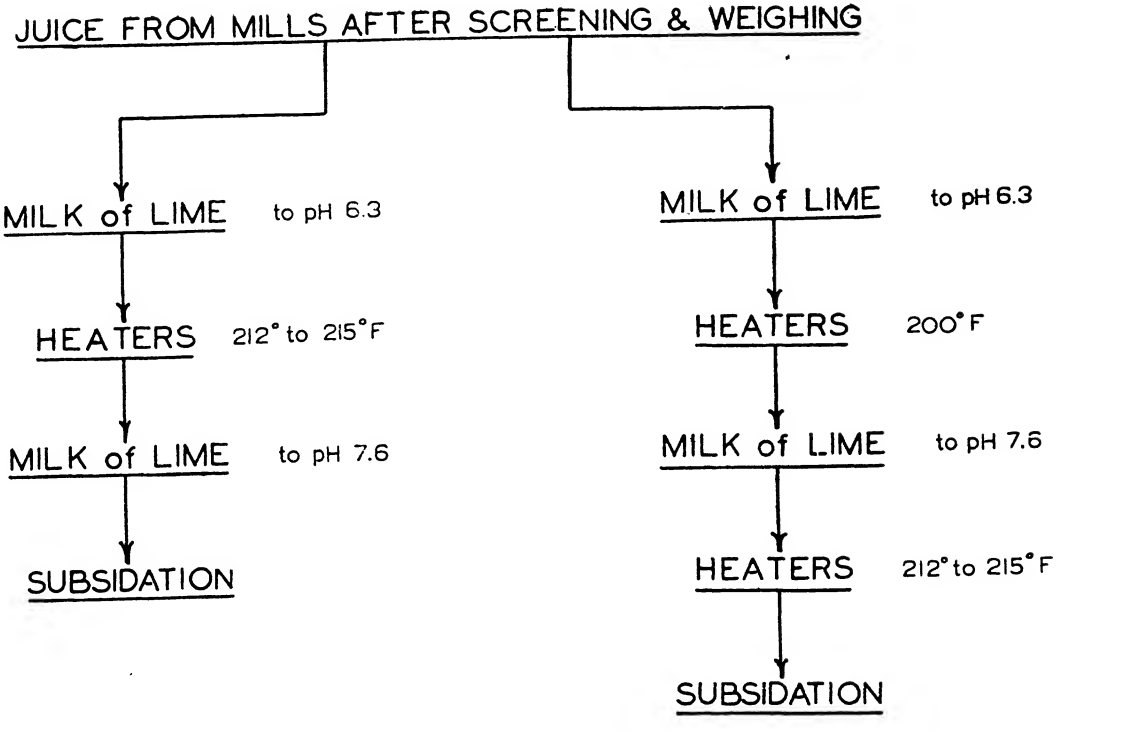


Fig. 8.—Alternative Raw Sugar Clarification Processes.

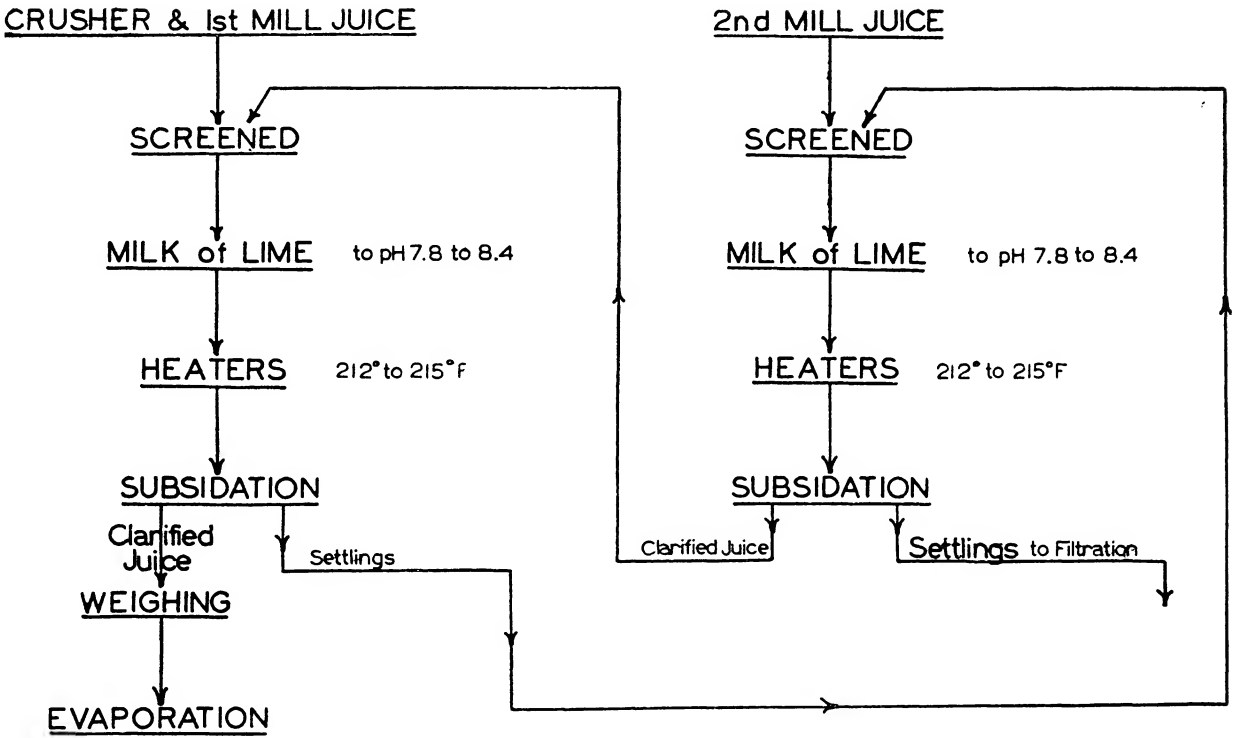
Note.—Processes (i) to (v) each use the mixed juice from the mills. There is no segregation of juices as in Process (vi). It will be seen that the essential differences lie in the frequency and order of applying the milk-of lime and heat.



(iv) FRACTIONAL LIMING

(v) FRACTIONAL LIMING & DOUBLE HEATING

Fig. 8 (cont).



(vi) COMPOUND CLARIFICATION

Fig. 8 (cont).

of lime after heating then brings about the formation of the precipitate of calcium phosphate, etc. In factory practice, it has been found that there may be difficulty in getting the precipitated material to settle properly.

Fractional Liming.

The raw juice is limed to *pH* 6·3, heated to 212° to 215°F. and further lime is added to the hot juice to *pH* 7·6. It is then settled in the subsiders. This is fundamentally the same as Hot Liming except that the juice is not so acid at the time of heating and there is less chance of sucrose loss by inversion.

Fractional Liming and Double Heating.

The raw juice is limed to *pH* 6·3, heated to 200°F., limed to *pH* 7·6, heated again to 212° to 215°F. and settled. It is therefore the same as Fractional Liming except that a second heating has been added. This has been found to be beneficial in increasing the rapidity of settling and reducing the volume of the settlings (muds). This and the last two processes (Hot Liming and Fractional Liming) will clarify nearly all types of juices with varying degrees of success. The especial advantages of this particular process are, however, not so apparent on good settling juices, e.g. BH 10(12) and B 726, as on refractory juices which settle with difficulty, e.g. POJ 2878.

Compound Clarification.

In this process, the juice from the crusher and 1st mill is known as the Primary Juice. The juice from the 2nd mill is known as the Secondary Juice. The Primary Juice is clarified by the cold liming process, and the settlings therefrom are mixed with the raw Secondary Juice which is dealt with similarly in a separate set of equipment. The clarified secondary juice is mixed with the raw primary juice prior to its treatment, and the secondary settlings are filtered. The clarified secondary juice is therefore re-settled and finally emerges as primary clarified juice. Similarly, the easily precipitated primary settlings after re-settling emerge as secondary settlings. The process gives good results with nearly all types of juice.

Liming the Juice.

Deposits of calcium carbonate are fairly common throughout the world, and it is usually possible to obtain locally the necessary

lime supply for the factory. There is, however, considerable variation in the purity of limestone, and from the sugar factory's point of view, the nature and amount of impurities are of extreme importance. Those most commonly found, together with their effects in the factory, are silica, iron oxide, alumina and sulphates which produce evaporator scale, magnesia which discolours the juice and retards settling, and carbonate which indicates an under-burnt or a stale lime, and therefore reduces its effectiveness.

Preparation of Milk-of-Lime.

Lime is used in the factory either in the form of burnt lime (Calcium Oxide) or of hydrated lime (Calcium Hydroxide). *Burnt lime* requires slaking in water before the suspension or milk is prepared. The *preparation*, which requires careful supervision, is carried out as follows : The fresh burnt lime is mixed with sufficient water to form a thick paste and allowed to stand for 12 to 24 hours. During this period the temperature rises considerably and, provided the mass does not tend to dry out due to insufficient water, thorough slaking is obtained. The paste is then diluted to three to four times its volume with water, thoroughly stirred and passed through a coarse mesh screen and then a fine (80-mesh) screen to remove the insoluble impurities. The resulting suspension is allowed to settle, and the water is decanted to remove the soluble impurities. Fresh water is then added, so that the final milk is obtained at the required density of 15° or 20°Bé.

The calcium oxide content of milk-of-lime at these two densities is as follows :

TABLE II.

°Baumé.	Weight milk lbs. per cu. ft.	Per cent. CaO.	Lbs. CaO per cu. ft.	Lbs. CaO per Imp. gal.
15	69·67	13·28	9·25	1·484
20	72·54	17·72	12·85	2·061

In the factory, it is more convenient to have one lime slaking tank discharging through the screens into either of two lime storage tanks. The settling, decanting and final dilution can be carried out in one of the storage tanks while the factory supply is drawn from the other, and so on alternately. Each tank should be of such capacity as to hold 36 hours' lime supply. *Hydrated lime* is burnt lime which has been slaked or hydrated

at the lime works. It is usually supplied either in air-tight drums or waxed paper bags, and prior to its addition to the juice it is only necessary to suspend the material in water and adjust to the desired density. The relative values of the two types of lime depend on the cost per lb. of available calcium oxide (CaO) at the factory, and the nature and extent of the impurities present. The calcium oxide content of hydrated lime is less than that of burnt lime, because in the former case water has already been added, hence an examination of the analysis is necessary before the cost can be calculated.

The Addition of Milk-of-Lime.

Milk-of-Lime is added to the juice for the reasons previously given.[1] At the conclusion of this step in the process, the whole volume of juice under treatment should be at a uniform reaction of the desired *pH* value. Such an accomplishment is, however, extremely difficult to obtain because of the small relative volume of milk-of-lime to be mixed with the juice. Methods of addition may be described as :

(*a*) Intermittent or batch ;
(*b*) Continuous.

The Intermittent or batch method consists in adding a specified lime volume to a definite juice volume (tank-full). Stirring is carried out either manually, or by means of mechanical stirrers or compressed air. Manual methods are for the most part inefficient. This can be demonstrated by taking samples of the juice at different levels at the discharge cock of the tank as it is being run out, and subjecting the samples to accurate *pH* tests. Certain mechanical stirrers, especially those rotating at a high number of revolutions per minute, can attain almost ideal mixing. Compressed air produces aeration of the juice and tends to delay settling. Whatever method is used, the mixing is improved if the lime is added proportionally as the tank fills. The practice of adding the whole of the required amount of milk-of-lime at one addition is to be deprecated. Apart from the mixing difficulty, the zone around the point of addition is made intensely alkaline, resulting in harmful effects on the juice constituents. Extreme care is therefore essential whichever batch method of addition is favoured.

[1] Page 33.

The Continuous method consists in adding a proportionate volume of milk-of-lime to the continually flowing juice in a pipe or a gutter or from a tank discharge. The devices used vary in design and principle. Those which meet the requirements most fully allow for manual or mechanical adjustment of the rate of flow of lime to suit changing juice quality, and for automatic adjustment of the rate of flow of lime to suit changing rates of juice flow. Other desirable features are that the device should be fool-proof, mechanically sturdy, and easily cleaned. The principle of continuous liming is sounder than that of the intermittent method, because much smaller volumes of both milk-of-lime and of juice are brought together. Also, the human element is to a large extent eliminated.

The amount of milk-of-lime of 15°Bé. required for raw sugar clarification varies over wide limits according to the type of juice and the process. An approximate figure is 0·5 per cent. by volume of juice or 1½ lbs. burnt lime per ton of cane.

Heating.

In olden days, heating was carried out in large open saucer-shaped copper vessels or *tayches* supported by brickwork over an open fire. The method is not only wasteful of heat, but leads to intense local overheating of the juice in contact with the sides of the vessel. Nowadays, all the heating and evaporation is carried out by means of steam.

Heater Construction.—A *heater* consists of a cylindrical shell placed either horizontally or vertically, and closed at either end by means of a brass or copper plate, known as a *tube plate*. Each tube plate serves to support one end of a series of *brass or copper tubes*. The tubes are arranged in nests or passes, the number of tubes per pass varying with the design. Steam is admitted through a suitable valve to the inside of the shell, and hence the outside of the tubes. Juice is pumped through the inside of the tubes and each tube plate is so divided that the juice flows down one pass of tubes, up the next and so on. The ends of the heater are closed by heavy metal doors. Heaters vary in diameter up to 5 feet and in length up to 30 feet. Suitable outlets are provided in the shell for entrained air and the condensed water.

Heater Capacity.—The capacity of a heater is measured in terms of the amount of heat (British Thermal Unit) transferred per unit of time. It depends on a variety of factors, the less technical ones of which include the pressure of the steam admitted, the velocity with which the juice is pumped through the tubes, the amount of scale or incrustation present on the inside or outside of the tubes, the efficiency with which the condensed steam and air is removed from the outside of the tubes and the amount of tube surface, i.e. the heating surface, in contact with the juice and steam. The greater the *steam pressure*, and therefore the steam temperature,[1] the greater will be the difference in temperature between the steam and the juice to be heated, and the greater will be the transmission of heat. This similarly increases with the *velocity* with which the juice is pumped through the tubes. The presence of *scale* acts as an insulator and therefore reduces the heat transmission. Less scale is formed on the inside of the tube at higher juice velocities than at lower juice velocities because of the scouring action.

The latest types of heater have *baffles* arranged inside the shell and between the tubes, so that the condensed water from the upper set of tubes does not gravitate on to the lower set. In this way, the lower tubes are kept free of immersion in water derived from the upper tubes, and the heat transmission is increased because water acts as a heat insulator. By carefully arranging the baffles, a further beneficial effect is obtained in that a definite path for the incoming steam is created. Any air present is therefore driven to one point where it can be removed by means of a vent. Air is also a heat insulator and "blankets off" the tubes, hence its presence prevents steam from coming into contact with them and no heating can take place. The greater the area of *heating surface* in contact with the juice and steam, the greater will be the heat transmission. The size of the heater to be installed also depends on the *amount of juice* to be heated and the *required temperature rise.* If heavy incrustation is a likelihood, additional capacity should be installed, so that all the heaters need not be used at once, and cleaning is possible without stopping the juice flow.

[1] Table I, Page 26.

CHAPTER IV.

Subsidation.

After treatment of the juice with lime and heat, separation of the precipitated impurities by subsidation is carried out in settling tanks, of which there are two types :

Intermittent or Batch.
Continuous.

Intermittent or Batch Type Clarifiers.

There are several variations in design and construction, but whatever form is used, it is the normal practice with intermittent subsidation to first settle the juice and, after decanting the clear supernatant liquid, to re-settle the subsided precipitate (settlings or mud). In this way the muds are concentrated, more juice is recovered, and there is less work for the filters to do. The first series of settling tanks are known as 1st clarifiers (see Fig. 9), and the second series as the 2nd clarifiers. The muds from the 1st clarifiers, which normally amount to 10 to 20 per cent. of the volume of the original juice, are collected in a 2nd clarifier and boiled with steam before re-subsidation. After decanting the clear juice, the 2nd clarifier muds are sent to the mud blow-up tank, which acts as a feed tank for the filters. The decanted juice from the 1st clarifiers is sent direct to the evaporator, while that obtained from the 2nd clarifiers is sent either to the liming tanks for re-treatment because of its opaque appearance or else direct to the evaporator with the first decanted juice.

Construction.—In shape, an intermittent settling tank is either rectangular with a sloping bottom or cylindrical with a conical bottom. A flat bottom is avoided because of the difficulty of obtaining clean drainage of the muds. The tank is filled with the hot treated juice through a pipe leading either to the top or to the bottom. Modern tendency is to use "bottom-filling" so that there is the least possible disturbance of the

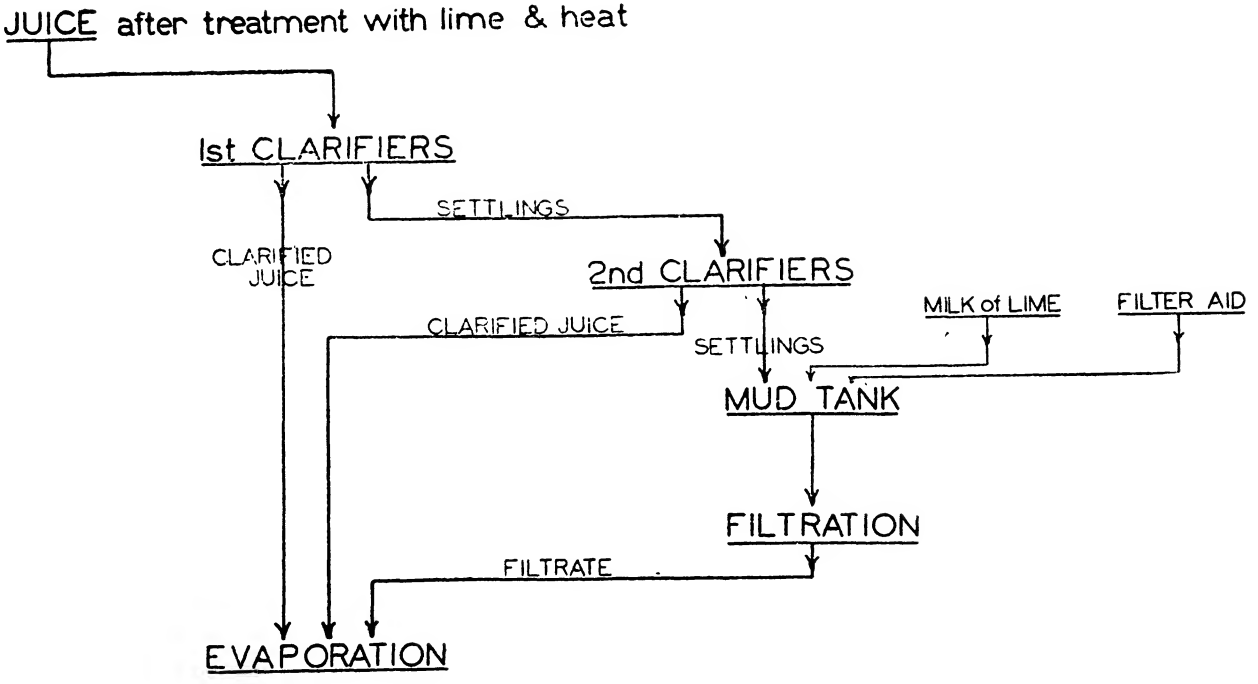


Fig. 9.--Subsidation in Intermittent Type Clarifiers.

juice within the tank due to created currents. The clear supernatant juice is decanted after settling by means of a series of cocks at different levels, or by means of a float device connected to a single cock. These discharge into one of two gutters, the clear juice gutter or the muddy juice gutter. A swivel device is attached to effect this change-over as required. Arrangements are such that clarified juice can be drawn off to the lowest level above the zone of mud. The mud is discharged through a pull-plug placed at the lowest point in the bottom.

Operation.—Each tank is filled separately, allowed to subside for ¾ to 1½ hours, then the clarified juice is decanted. The actual operation of an individual tank is nothing more than the intelligent operation of the various valves and cocks. It is obvious, for example, that only clear clarified juice should be allowed to flow into the clear juice gutter. Intermittent settling tanks do, however, have certain operating advantages. One is that provided the number of units is carefully chosen, a tank of juice which settles with difficulty can be cut out of circuit without an undue effect on the capacity of the station. Another advantage is the flexibility of operation, in that the number of units in use can be regulated according to the grinding rate of the mill. As opposed to these, the chief disadvantages are the amount of floor space required and the higher operating labour costs.

Continuous Clarifiers.

In this type of clarifier, the hot treated juice is pumped into the tank, and clarified juice and mud are constantly withdrawn from it. The method by which the separation of the precipitated impurities from the clarified juice is accomplished varies. Generally, one of two methods is employed ; either the juice is settled in a series of interconnected, superimposed shallow trays, or the direction of flow of the incoming juice is suddenly changed by means of baffles, so that the precipitate is thrown off by centrifugal force.

Construction.—Within the last few years about 20 continuous clarifiers have been patented, and it is not within the scope of this work to describe their varied construction. Some operate as individual units, while others require to be used in series of two or three in order to obtain an acceptable clarified juice.

Operation.—The operating features of this type are the small floor space which is required and the low labour costs. Conversely, the disadvantages are that the equipment must be operated at or near its designed capacity and, in certain cases, under the specified conditions of temperature and pressure. Generally speaking, the system of juice and mud flow is in a delicate state of equilibrium, and any change in the conditions upsets this system. Also, a juice which settles with difficulty is apt to contaminate the discharged clarified juice for a greater period than if it were settled separately. Certain types discharge a mud which is dense enough to preclude the use of second clarifiers, and it is therefore discharged direct to the mud blow-up tank prior to filtration. This decreases the time that part of the juice is in process and helps to reduce the possibility of sucrose losses by inversion. Against this is the fact that not all types can claim a complete change of juice periodically within the vessel during operation. Stagnation and bye-passing may occur, leading to inversion losses and acidity. Such a condition can only be arrested at such time that it is possible to empty or liquidate the whole equipment. A technical advantage of importance is that the temperature drop between incoming and outgoing juice is usually small, of the order of 10°F. Hence the feed to the evaporator is at a high temperature, leading to heat economy and the saving of fuel.

CHAPTER V.

Filtration.

It has previously been pointed out that the greater part of the separation of the precipitated impurities from the juice is accomplished by means of simple subsidation. Subsidation is still the cheapest and most efficient method for this purpose in raw sugar manufacture. The separation is completed by means of filtration of the final settlings. In certain processes of white sugar manufacture, the whole of the juice is filtered. In that case, the filtration is carried out using the same type of equipment as is used to filter the muds in the raw sugar process.

Mechanism of Filtration.

Mud consists of the precipitated impurities suspended in a relatively small volume of juice. The particles of the precipitate are irregular in shape and size and can best be thought of as small, irregular pieces of jelly-like material. It can therefore be seen that the influence of undue pressure will compress the particles into a solid mass through which it is impossible for a liquid to drain. Elaborating this statement : in commercial filtration, whatever the type of filter, the suspension of mud particles in juice is made to flow by positive or negative pressure (that is, by force pump or vacuum) on to a cloth or fine metal screen. The mud particles are retained and the liquid passes on. The cloth or fine screen does not itself carry out the filtration, but acts merely as a foundation for the mud particles themselves to form the filter bed. The spaces between the weave of the cloth or the holes in the metal screen are big enough to allow particles to pass through. As the first layer impinges on the cloth, some are actually carried away by the liquid and the filtrate is cloudy. Others adhere to the cloth or screen. With the laying down of subsequent layers a porous bed is eventually formed

so that from that point onwards the particles are filtering themselves. With increasing pressure applied to the mud, the particles tend more and more to lose their original shape and eventually may become flat. It is obvious that conditions of this nature will entirely destroy the porosity, and the flow of the liquid (juice) through the bed (cake) will cease. Similarly, if the original layers of the bed are laid down under high pressure the same effect is evident. There is a so-called *critical pressure* for every filterable material of this nature, above which "flattening out" is obtained, and any further increase in pressure produces no further filtrate flow. In practice, the critical pressure should, of course, never be approached. In order to retain cake porosity and increase the rate of filtration, certain inert substances known as *Filter Aids* may be added. Filter aids are derived from diatomaceous earth and consist of small porous particles of silica. By addition of a filter aid to the mud before filtration, the particles become dispersed throughout the cake as it is laid down and tend to prevent "flattening out." In the cane sugar factory, fine bagasse flour can be used for the same purpose. Whatever type of filter is used, therefore, it is essential that there should never be malformation of the particles due to the use of too high a feed pressure.

Filter Types.

Filters vary widely in design according to the type of material to be filtered. The raw cane sugar industry employs a variety of types, of which the following are most frequently used :

Plate-and-Frame Filter Presses ;
Continuous Rotary Drum Vacuum Filters.

There are also various kinds of leaf and bag filters. The plate-and-frame filter press may be called the universal equipment, but it is gradually being ousted from this position by the more efficient and economical continuous rotary filter. These two filters are described herewith :

Plate-and-Frame Filter Press.

Construction.—This filter consists of a series of alternate cast iron plates and frames supported on side members. A plate is a rectangular piece of metal of varying dimensions and ½ in. to

1 in. thick. Each of its two major surfaces is formed of channels or small pyramids to facilitate drainage of the filtrate to an internal slot at one corner connected to a discharge cock. There is attached a side-lug or eye which coincides with similar lugs on each plate and frame in the press. A frame is a rectangular piece of metal like an empty picture frame, fitted with side-lugs

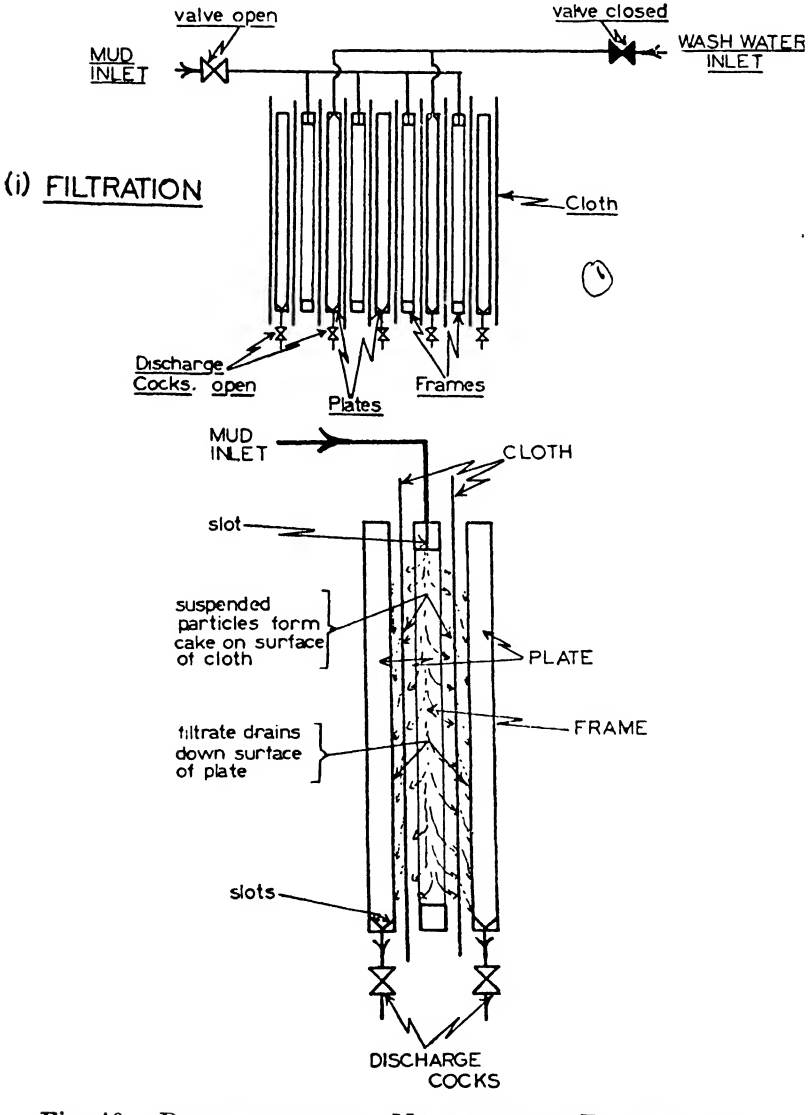


Fig. 10.—Diagram showing Mechanism of Filtration in a Filter Press.

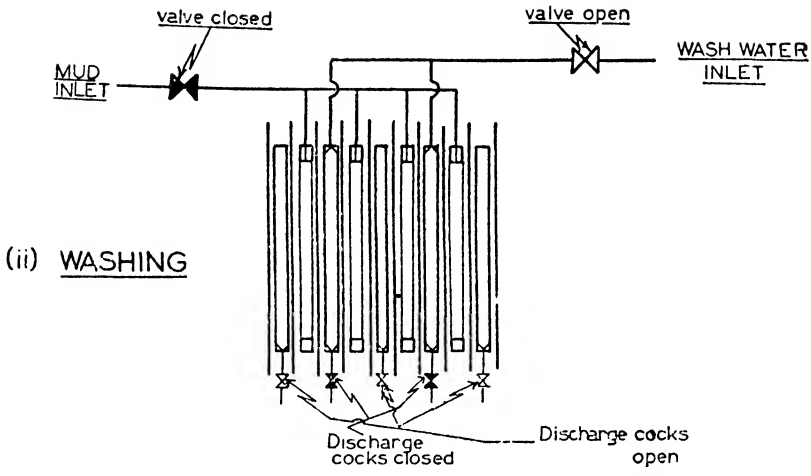


Fig. 10a.—Diagram showing Mechanism of Washing the Cake in a Filter Press.

but without a drainage cock. The surfaces of the frames are made to face accurately with similar raised surfaces on the co-acting plate. The actual joint between the two is made by the edge of the filter cloth which is spread or dressed on each plate. Pressure is applied to make the joints leak-proof by tightening the plates and the frames between a fixed and a moveable filtering head. The side-lugs or eyes in each plate and frame then form a continuous pipe through which the mud or wash water can be pumped into the filter. There are small internal slot connections between the mud lugs and each frame, so that the mud flows into the frame, the cake is formed on the cloth, the filtrate passes through to the drainage surfaces of the plate and flows out through the discharge cock (see Fig. 10 (*i*)). The filtrate is discharged into a gutter placed under the cocks. For washing the cake, alternate plates are made with internal slots connecting to the wash water line through another set of side lugs or eyes.

Operation.—The mud from the 2nd clarifiers is discharged into the *mud blow-up tank.* This tank is equipped with an "open" steam coil, i.e. the steam from the coil passes through a series of small holes drilled in its underside and thus mixes with the mud. Lime suspension may or may not be added to

the mud to a reaction of *pH* 8.4 to 8.6 or more. The mud is then boiled. This preparatory treatment holds good for mud from both intermittent and continuous clarifiers. Filtration is started by opening the mud valve on the filter press very slightly and then starting the mud pump. The reason for only opening the mud valve very slightly is that at this early stage the flocs must not in any way be deformed or flattened by the use of too high a pressure. After the filtrate begins to run bright and clear, the mud valve is further opened, but again very cautiously. The successful starting of a filter press is skilled work, especially if the frames are to finish filled with a hard dry cake. Difficulties arise when several filters are fed by the same pump, because the mud flows to the filter working under the lowest pressure, i.e. the one which is the least full, and the filter which is almost full is starved. This can be overcome by the use of a *Double Pressure System*, in which each filter is connected through suitable valves to two mud feed pipes, one delivering thick mud at low pressure (15 lbs. per sq. in.) for forming the cake, and the other thin or diluted mud at high pressure (45 lbs. per sq. in.) for finishing off.

When the flow of the filtrate is at a minimum *washing* is commenced. First the mud valve is closed, then alternate discharge cocks (those on the plates with slot connections to the water lugs) are shut and the water valve is opened. The wash water then enters the plate on each side, passes through the cloth, the mud in the frame and the cloth on the next plate and drains away through the open discharge cock (see Fig. 10a). The lower the pressure at which the cake is formed, the easier is the washing and the less the liability to channelling. Channelling is said to have occurred when all the wash water flows through one path or channel in the cake instead of evenly diffusing through the whole mass. Washing may be considered as a process of gradual dilution of the juice left in the cake, hence the longer the washing the more dilute the remaining juice and the lower the sugar loss. It is to be remembered, however, that all the water used for washing must sooner or later be removed by evaporation. Another limiting factor to the time of washing is the available filter capacity, because during this part of the cycle no mud is being filtered. Steam is sometimes used instead of

wash water. A more elaborate washing system is that known as *Double Filtration* which utilizes two sets of filter presses. The first operate in exactly the same way as described above, except that little or no washing is carried out in them. The mud is then removed, re-suspended in water in a tank fitted with stirring gear, heated and pumped to the second set of filters. It can be seen, therefore, that the second set of filters is maintained and operated solely for washing purposes. The system is therefore expensive to operate and only considered justifiable when the value of the recovered sugar pays for the extra operating charges.

After washing, the filter press is opened and the cake removed from each frame. The cloth may or may not be removed and washed after each cycle—the usual period of use is to wash the cloths once per day or twice per week. As the cake is being removed or "cut-down," the mud slot to each frame must be cleaned out, otherwise small pieces of bagasse are liable to cause a blockage. This results in uneven pressure and the eventual breakage of the adjoining plate. The opening and shutting of the plates and frames cause severe mechanical wear on the filter cloths, which can be reduced to some extent by a covering of Burlap. This covering does not in any way hinder filtration.

Continuous Rotary Drum Vacuum Filter.

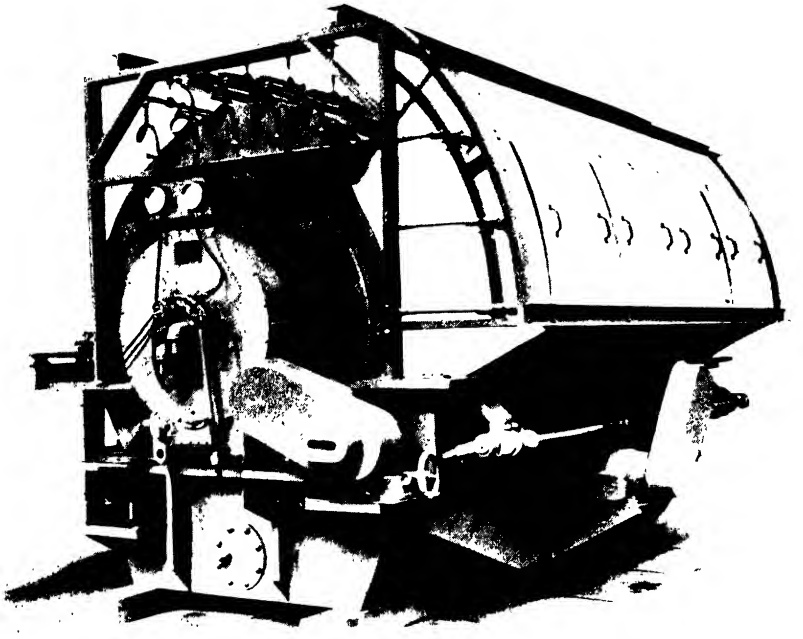
Construction.—These filters vary somewhat in the detail of their design, but the underlying principle is as follows : There is a large horizontal drum, the surface of which is divided up longitudinally into several sections. As the drum slowly revolves, each section automatically carries out a part of the filtering cycle. The automatic action is produced by a valve of special design. It controls the pressure or vacuum, the discharge of the filtrate, etc., of each section in all parts of the cycle. One cycle is completed in each revolution of the drum. Usually the bottom of the drum dips into a feed tank and the cycle of a section just entering this tank is (*a*) laying down the cake (cloudy filtrate) ; (*b*) building the cake (bright filtrate) ; (*c*) air displacement of juice ; (*d*) washing (sprays) ; (*e*) drying ; and (*f*) discharge.

Operation.—Once the filter is started, and since the operation is continuous and automatic, there is little to be done except routine checking of mud temperature, mud level, etc. An important factor is the maintenance of the desirable amount of suspended solids in the mud to ensure correct cake characteristics. The operating labour cost is small compared to filter presses, the station is kept much cleaner, cloth consumption is reduced, less floor space is required and there is a lower sucrose loss in cake.

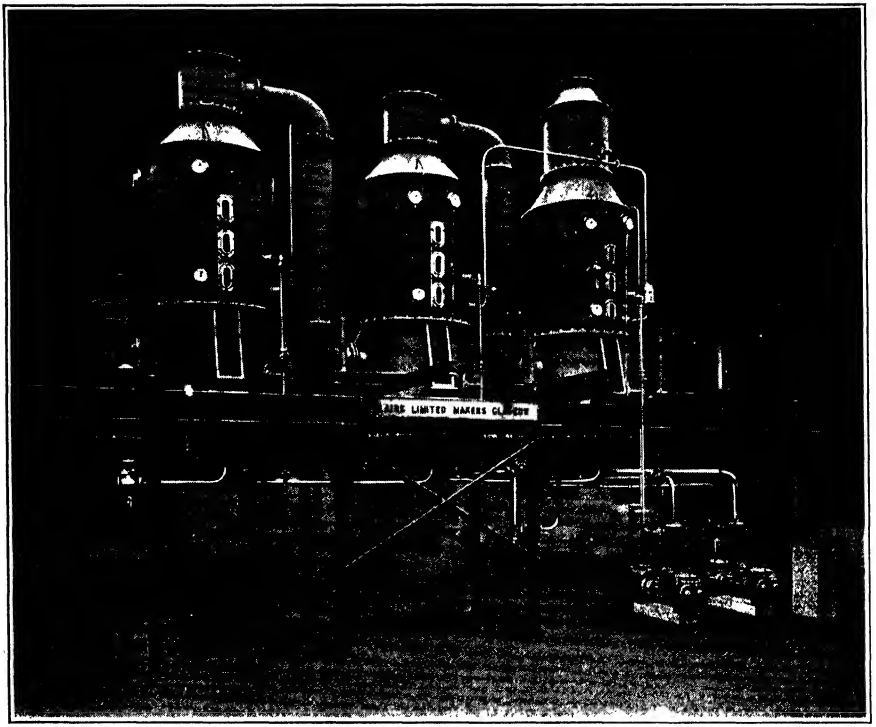
Filter Products.

The precipitated impurities, after removal by filtration, form a cake of varying moisture content. The cake from a rotary vacuum filter is generally drier than the cake from a filter press. After removal from the filtering surface, the cake is sampled and weighed (see Chapter XIII). It is used as a manurial dressing in the cultivation (see Chapter XII).

The filtrate from the filter is sent either direct to the evaporator, with the clarified juice from the 1st and 2nd clarifiers, or to the liming tanks for re-treatment. Its lime content is high, and the latter alternative may therefore be looked upon as an economy, since it will help to reduce the amount of milk-of-lime to be used. As opposed to this, the pumps, heaters and clarifiers must have capacity sufficient to deal with the extra volume of juice leaving the liming tanks.



Continuous Rotary Drum Vacuum Filter
(Oliver-United Filters, Inc.)



TRIPLE EFFECT EVAPORATOR.

(*Blairs Ltd.*)

CHAPTER VI.

Multiple Effect Evaporation.

Clarified juice is a dilute solution of sucrose and other substances. Before crystallization of the sucrose can take place the greater part of the water must be removed. Water removal is carried out in the factory by means of steam heated evaporators. There are two stages. The first is by multiple effect evaporation and the second by single effect evaporation in what are known as vacuum pans. Formerly, the processes of evaporation and crystallization were carried out simultaneously in large open copper-shaped vessels known as tayches. A series of two to four were built into a brick flue between an open fire and the chimney. The juice was ladled from one tayche to the next, finishing in the one over the fire. Such a method is not consistent with the modern need for efficiency and economy.

Principles of Evaporation by Steam.

The principle underlying evaporation by steam or vapour is that when the steam impinges on a surface at a lower temperature than itself, heat flows from the steam to the substance on the other side of the surface. In so doing the steam condenses and releases its latent heat (See Chapter II). Since a definite amount of heat is required to evaporate a certain weight of water under specific conditions, the operation of an evaporator is one of the transference of latent heat from the steam to the boiling juice.

Multiple and Single Effect Evaporation.

Multiple effect evaporation is used in the first stage of the water removal due to (1) the steam economy of the system, and (2) strict control of boiling conditions not being necessary. An evaporator is of the *multiple effect type* when juice in a second vessel is boiled by virtue of the condensation of vapours derived from boiling juice in a first vessel. The juice in the first vessel is boiled

by the condensation of steam.[1] The process is repeated in the subsequent vessels comprising the evaporator. Hence it can be seen that the consumption of steam is limited to the requirements of the first vessel only. The more vessels there are in the evaporator the greater the steam economy, although the number cannot be made indefinite because of certain technical considerations. It is usually limited to three, four, five or six. The temperature difference necessary for the flow of heat from the steam or vapour to the juice is brought about by the creation of a gradually decreasing temperature gradient through the series of vessels. Such a temperature gradient is in turn created by a pressure gradient, the pressures being less than atmospheric. The use of pressures greater than atmospheric would be equally effective, but this would involve temperatures too high to avoid sucrose destruction. *A single effect evaporator* consists of one vessel only. Heat is supplied by steam and the vapours rising from the boiling liquor are condensed, i.e., the heat contained therein is not utilized. The steam consumption per pound of water evaporated is therefore greater than in a multiple effect evaporator. The control of the temperatures and pressure in such a vessel is however very much more delicate and it is for this reason that vacuum pans are used for the highly skilled task of crystallization. (See Chapter VII).

The Multiple Effect Evaporator.

Construction and Arrangement.

The evaporators most commonly found in use in the cane sugar industry consist of three or four vessels and are known as Triple or Quadruple effects respectively. Apart from the number of vessels, both are exactly the same in construction and operating principles, the quadruple being an elaboration of the triple effect and giving greater heat economy. Each vessel of an evaporator is essentially the same in construction as any other. It consists of a vertical cast iron, copper or metal plate cylindrical *body* which is closed at the top by a *dome* and *catch-all* (see Entrainment)[2] and at the bottom by a *saucer*. The heating element is a large

[1] *Steam* is water in the gaseous state at a pressure greater than that of atmospheric. The word *vapour* is used to describe steam at a pressure less than that of atmospheric although it may be used in reference to steam at pressures slightly above atmospheric and especially when it is formed from boiling juice in a closed vessel. In evaporator practice, the terminology is such that *steam* enters the 1st calandria but *vapour* arises from each of the boiling vessels irrespective of the pressure or vacuum therein.

[2] Page 65.

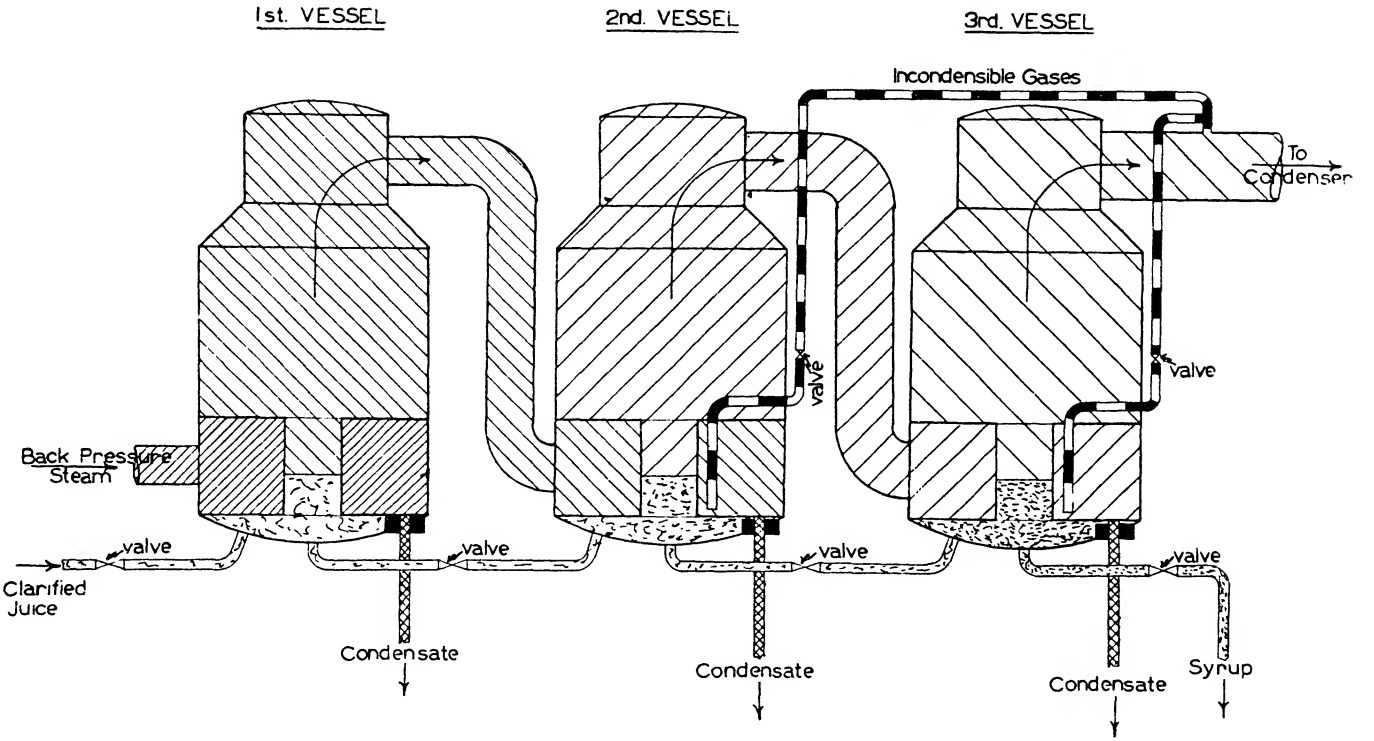


Fig. 11.—Diagrammatic Flow Sheet of Juice Vapours, Incondensible Gases and Condensate in a Triple Effect Evaporator.

drum-shaped structure known as a *calandria* which fits into the lower part of the body of the vessel just above the saucer. The top and the bottom of the calandria are known as the top and the bottom *tube plates* respectively. They are interconnected by a series of copper, brass or steel tubes, three to six feet long, the ends of which are fitted into holes in the plates. There is one tube of large diameter placed either centrally or off-set. Its purpose is to promote circulation and it is known as the *downtake*. The vertical sides of the calandria may either form an integral part of the sides of the vessel or the calandria may be "floating." A floating calandria is one in which there is space left between it and the vertical sides of the vessel. The space in the body of the vessel between the top tube plate and the dome is known as the *vapour space*. The space between the bottom tube plate and the saucer and inside the calandria tubes is known as the *liquor space*. The calandria of the first vessel (See Figure 11), is connected to the back pressure steam main which supplies it with low pressure steam through a valve. The vapour space of the first vessel is connected from the dome by a vapour pipe to the calandria of the second vessel to supply it with vapours from the boiling juice. Similarly, the vapour space of the second vessel supplies the calandria of the third vessel with vapours through a vapour pipe. The vapour space of the third vessel of a Triple Effect Evaporator is connected to the *condenser*. The condenser, as described later,[1] condenses the vapours by bringing them into intimate contact with cold water. *Incondensible gases* derived from the boiling juice in the first and second vessels are vented from the apparatus through *ammonia tubes*, and together with those from the third vessel and air released from the condenser cooling water, are removed by means of the *vacuum pump*.[2] As evaporation proceeds, steam condenses in the first calandria and vapour in the second and third calandrias. The condensate in the first calandria which is under pressure is removed by a low pressure steam trap. The condensate in the second and third calandrias is removed by means of pumps, traps or inverted syphons, because these calandrias are under vacuum (See Condensate Removal).[3] Juice is fed to the first vessel by pump or gravity feed. It is transferred from the first to the second vessel and from the second vessel to the third by virtue

[1] Page 69. [2] Pages 64, 71. [3] Page 69.

of the differences in pressure existing in the vessels (See Table V and Figure 12). The flow takes place through suitable pipes and is controlled by feed valves. The high density syrup accumulating in the third vessel is evacuated by a pump. Each vessel is also fitted with two manhole doors, one above and one below the calandria, with sight glasses for inspection of the boiling liquor, with pressure or vacuum gauges and thermometers, and the outside is lagged and covered with wooden slats to reduce the loss of heat by radiation. Generally, the evaporator is worked in parallel current operation, that is both the juices and the vapours travel in the same direction. The juice enters the first vessel at a density of 12° Brix to 15° Brix (specific gravity 1·048 to 1·061) and is evacuated from the last vessel after concentration at a density of 49° Brix to 63° Brix (specific gravity 1·225 to 1·305, 27° to 34° Baumé). Since the juice must eventually be concentrated in the Crystallization process to the density of the finished massecuite, it is economical to carry the first stage, in multiple effect evaporation, as far as possible without crystallization occurring. The result is increased heat economy because there is less work for the vacuum pans which operate in single effect.

Measurement of Pressure.

Atmospheric pressure is read on a gauge as 0 lbs. per sq. inch gauge. If the gauge is connected to a vessel from which all air is completely exhausted, the reading would be —14·7 lbs. per sq. inch. This is known as absolute zero or 0 lbs. per sq. inch absolute. Hence atmospheric pressure is 14·7 lbs. per sq. inch absolute. Another method of measuring the atmospheric pressure is by means of a column of mercury. Under normal conditions of atmospheric pressure, such a column would read 30 inches, provided the space in the unoccupied part of the tube containing the mercury is an absolute vacuum. Engineering practice measures

Table III.

	Gauge Pressure. lbs./sq. in.	Absolute Pressure. lbs./sq. in.	in. Mercury.	Inches of Vacuum.
	100	114·7	—	—
	50	64·7	—	—
Atmospheric Pressure	0	14·7	30	0
	—	10·0	20½	9½
	—	5·0	10¼	19¾
	—	0·0	0	30

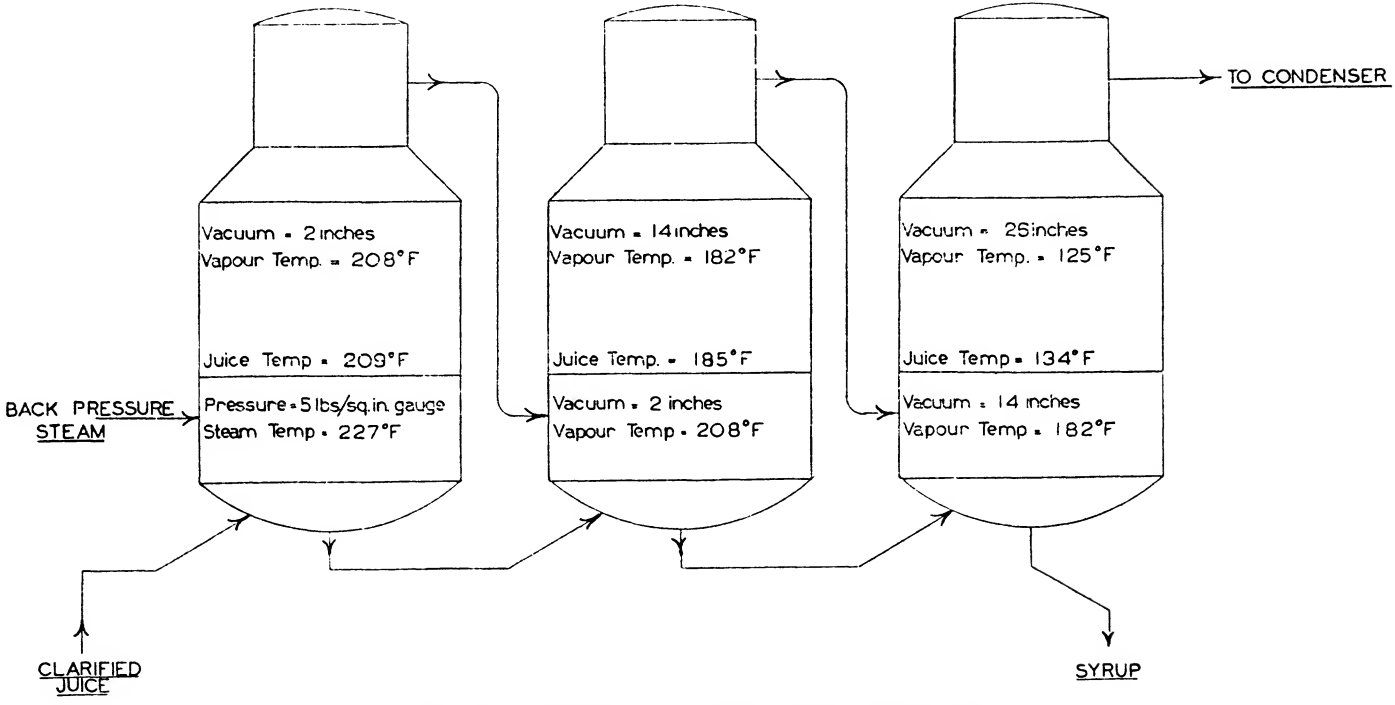


Fig. 12.—Evaporator Operating Conditions.

the vacuum created in a vessel as the difference between the mercury column reading of the vessel's atmosphere and 30 inches. For example, assume a partial vacuum is created in an evaporator vessel and a mercury column in that vessel reads 12 inches. This would be referred to as 30 — 12 = 18 inches of vacuum. Table III shows the relationships between these various scales.

It will be noticed that absolute pressure measured in lbs. per sq. inch is the only scale which measures pressures both above and below atmospheric.

Relationship between Temperature, Pressure and Latent Heat.

The lower the pressure in a vessel, the lower the temperature at which water in it will boil. Assuming the water is at the temperature at which it will boil (see Chapter II), the latent heat required per lb. of water increases with decreasing pressure. See Table IV.

Table IV.

Absolute Pressure. lbs./sq in.	In. Mercury.	Inches of Vacuum.	B.P. of Water, °F.	Latent Heat, B.T.U. per lb.
14·7	30	0	212	965·7
10·0	20½	9½	193	979·0
5·0	10¼	19¾	162	1000·7
0·0	0	30	32	1091·7

Factors affecting the Heat Transmission.

The amount of heat which flows from the steam or vapour on one side of a calandria tube to the boiling juice on the other side depends on a number of factors. These factors are in turn dependent on others. They are discussed herewith :

Temperature Difference.

The greater the difference between the temperature of the steam or vapour and that of the juice, the greater will be the heat transmission. The level of the temperature difference is also of significance. For example, assume steam is supplied at 220°F. to boil juice at 200°F., the heat transmission is greater than when vapour is supplied at 170°F. to boil juice at 150°F., although the temperature difference, namely 20°F., is the same in each case. It has been shown that the temperature of the steam or vapour depends on the pressure. Similarly, the temperature at which the liquid boils depends on the pressure. In the evaporation of

cane juices in a multiple effect evaporator two adverse factors are introduced which influence the temperature at which the juice boils. Cane juice contains substances in solution. The effect of these substances is that the juice boils at a temperature higher than that of water under similar conditions of pressure. Such an effect is known as *Boiling Point Elevation* (B.P.E.). The boiling point elevation is greater the greater the amount of dissolved substances. Also, the amount of elevation is constant irrespective of the pressure. For example, a cane syrup may boil at 230°F. at atmospheric pressure while water boils at 212°F. The boiling point elevation is 230 — 212 = 18°F. At 19¾ inches of vacuum water boils at 162°F. (See Table IV). The cane syrup would therefore boil at 162 + 18 = 180°F. In evaporator operation, the effect of boiling point elevation is aggravated in the last vessel because of the increased density of the syrup. The second factor is *Hydrostatic Head.* The pressure exerted on the juice at the surface in a calandria tube is less than that exerted at the bottom. Hence the temperature at which the juice boils varies with its position in the tube. Again, the effect is aggravated in the last vessel of the evaporator.

Surface Fouling.

The deposition of scale on the tubes (See Scale and Scale Removal)[1] acts as a heat insulator. When the surfaces are clean, very much more heat is transmitted than when they become fouled. The reduction in heat transmission depends on the thickness and composition of the scale, which is found at its worst in the ultimate vessel.

Incondensible Gas and Condensate.

Both incondensible gas and condensate act as a heat insulator. Their presence within the calandria lowers the heat transmission. Methods of removal are discussed later.[2]

Rate of Circulation.

Heat transmission increases with the rate at which the juice circulates over the heating surface. Circulation depends on the design and proportioning of the evaporator vessel, and on the character and viscosity of the heated liquid. The viscosity of cane

[1] Page 72. [2] Page 66.

juice increases with the concentration, hence its detrimental effect is greatest in the last vessel. Adequate circulation is ensured by the downtake, in which no heating takes place. The boiling liquid rises through the calandria tubes, releases its vapour and descends the downtake into the saucer again.

Heating Surface Material.

Within factory limits, there is little effect on heat transmission of either the kind or the thickness of the material used for making the heating surface.

Heat transmission is measured and expressed as the amount of heat in B.T.U. which flows through a square foot of heating surface in one hour for each degree Fahrenheit difference in temperature of the steam and boiling liquid.

Evaporator Operation.

The average conditions of temperature and pressure under which the three vessels of a Triple Effect Evaporator operate are as follows :—

Table V.

	1st vessel.	2nd vessel.	3rd. vessel.
Calandria :			
Absolute Pressure, lbs./sq. inch	19·7	13·7	7·84
,, ,, inches of vacuum	—	2	14
Temperature of vapour, °F.	227	208	182
Vapour Space :			
Absolute Pressure, lbs./sq. inch	13·7	7·84	1·96
,, ,, inches of vacuum	2	14	26
Temperature of liquor, °F.	209	185	134
,, ,, vapour, °F.	208	182	125
B.P.E. of liquor, °F.	1	3	9

It can be seen that conditions of vapour pressure and temperature are the same in the first vapour space and second calandria and the second vapour space and third calandria (See Figure 12). The first calandria derives its steam from the back pressure steam main and the third vessel passes its vapours to the condenser. The difference in temperature between the steam in the first calandria and the vapour in the third vapour space is known as the *Overall Temperature Difference*, which has to be divided, as

seen in Table V, between the three vessels. Since these two temperatures are set by certain technical considerations, in a quadruple effect the same overall difference must be divided amongst four vessels, thus leaving a smaller margin in each. In order that the effects of increasing boiling point elevation and other factors are overcome, it will be noticed that the difference between the temperature of the vapour in the calandria and the boiling point of the liquor in the vessel increases from the first to the third vessel. The reduction in pressure, or the creation of a vacuum, is brought about by the use of a vacuum pump connected to all vessels. On starting up, the pump merely exhausts the air contained in the apparatus. When boiling is in progress, the vacuum in any one vessel is maintained by two factors : (1) the condensation of the vapours supplied to the calandria of the next vessel ; and (2) the removal of the incondensible gases by the vacuum pump.

The multiple effect evaporator requires continuous and smooth conditions for its optimum operation. When the rate of juice intake and withdrawal from each vessel fluctuates within small limits only, the vapour demand and supply is stabilized and there is a minimum of variation in temperatures and vacua. Hence the experienced operator sets the juice control valves so that the volume of liquor in each vessel is constant. The level to be maintained is such that the top tube plate is sufficiently wetted but not submerged. A higher level is to be avoided, because the rate of evaporation is materially reduced, and the possibility of entrainment is increased.

The operation of an evaporator may be expressed either as the pounds of water evaporated per pound of steam supplied or as the pounds of water evaporated per square foot of heating surface.

The pounds of water evaporated from the juice per pound of steam supplied is largely controlled, for any one evaporator, by the temperature of the incoming feed into the first vessel. Referring to Table V, it is seen that the juice or liquor in the first vessel is boiling at a temperature of 209°F. If the temperature of the feed is less than 209°F., then it must be heated before boiling can take place. Such a condition is usually the case in practice.

Heating the feed is most economically carried out prior to its introduction into the first vessel. It is then supplied at or near the temperature of boiling and very little, if any, steam is used in the evaporator for heating purposes. Since the juice is heated to 212°F. during the clarification process, any reduction in temperature prior to evaporation is heat lost. The heat loss may be reduced by the use of efficient insulation on the clarifiers.

A condition which benefits operation is when the feed to a vessel is at a temperature higher than the liquor boiling in that vessel. Reference to Table V shows such to be the case when juice is fed from the first to the second vessel and from the second to the third vessel. Assume that 1 pound of juice is transferred from the first to the second vessel, the total sensible heat in the juice in the first vessel is 177 B.T.U. per pound and in the second 152 B.T.U. per pound. Therefore in transferring the juice from the first to the second vessel, 177 — 152 = 25 B.T.U. per pound are released. They are utilized in the formation of vapour, which is used in the calandria of the following vessel. The phenomenon is known as *flash or self-ebullition*. The results of this simple calculation are rather more interesting when carried out on a basis of 100,000 pounds of juice per hour and for both transfers of juice instead of one. Such a juice rate is the approximate equivalent of grinding 45 long tons of cane per hour.

Entrainment.

Entrainment is the mechanical carrying-over of small drops of liquor by the vapours released from the boiling juice. When boiling is taking place small bubbles of vapour are formed in the liquor. They ascend the calandria tubes and are released at the surface with a certain velocity. Small drops of liquor are thereby formed which are ejected into the vapour stream. If the velocity is great enough in relation to the height of the vapour space and the size of the drop, some of the drops may be borne away by the stream of vapour into the vapour pipe leading to the next vessel or condenser. Usually, there is a baffle device known as a *catch-all* or separator built into the dome of the vessel for the purpose of separating the drops from the vapour. Entrainment is caused by a variety of factors but most evaporator designs are such that if operating levels, etc., are correct, there is little danger

of appreciable entrainment taking place. Heavy entrainment occurs however, when, after a short stoppage, vacuum is restored rapidly. This is due to violent self-ebullition, resulting in the sudden formation of large volumes of vapour. The occurrence of entrainment in the last vessel is the most serious because of the high density of the liquor.

Incondensible Gas Removal.

Under operating conditions, the incondensible gas entering the apparatus is swept along by the vapour stream so that it tends to accumulate in certain zones or pockets in the calandria. Wherever gas accumulates, vapour is unable to impinge on the heating surface and no heat transmission can take place. Such an effect is known as "blanketing-off". Modern designs of calandrias are baffled and provide lanes down which the vapours are led, so that the incondensible gases are driven to a definite point or points. The task of removal is then very much simplified. It is considered good practice to lead the incondensible gas pipe, or ammonia tube, from the second and subsequent calandrias to the dome of the last vessel (See Figure 11). Each pipe is supplied with a valve which should be opened an amount just sufficient for the removal of all the gas, but which precludes the removal of vapour as well. It is extremely important for the efficient operation of the equipment that the incondensible gas removal should be as complete as possible, because the presence of such gas plays no beneficial part of any kind in the heat exchange which takes place.

Condensate Removal.

Efficient condensate removal is equally essential. If condensate is allowed to accumulate a similar blanketing-off is brought about, since water is a poor conductor of heat. Condensate removal from calandrias which are under pressure (i.e., a 1st vessel calandria) is carried out by the use of low pressure steam traps. Condensate removal from calandrias which are under vacuum (i.e., 2nd, 3rd and 4th vessel calandrias) is carried out by one of the three methods which are shown diagrammatically in Figure 13 :—

1. By traps or pumps.
2. By barometric drains.
3. By "U" syphons.

Whichever system is used, the important point is that positive action should always be obtained. *Traps and pumps* both require a certain amount of attention and are liable to valve leakage, etc., but certain designs of each type are extremely reliable. An advantage with traps is that each time they "fire," a certain volume of water is ejected, so that the rate of condensation is easily checked. The same is true of a pump connected to a float-controlled receiver. Usually there is one trap or pump connected to each calandria by a pipe. With all traps and some types of pump it is necessary to have a pressure equalizing pipe connected to the top of the calandria, so that the condensate can flow by gravity. If this is not installed, the device may become air-bound. The use of *barometric drains* provides a simple method of removal. A pipe connected to the calandria is water-sealed at its lower open end, so that a water barometer is created therein when vacuum is raised. Condensate then flows to the water level in the pipe and displaces a like amount into the water seal. The height of the drain depends on the calandria vacuum. Each inch of vacuum is equal to 1·15 ft. of water barometer. Thus, a calandria working under 15 in. vacuum requires (15 × 1·15) + 4 feet = 21·25 feet between the level of the bottom of the calandria

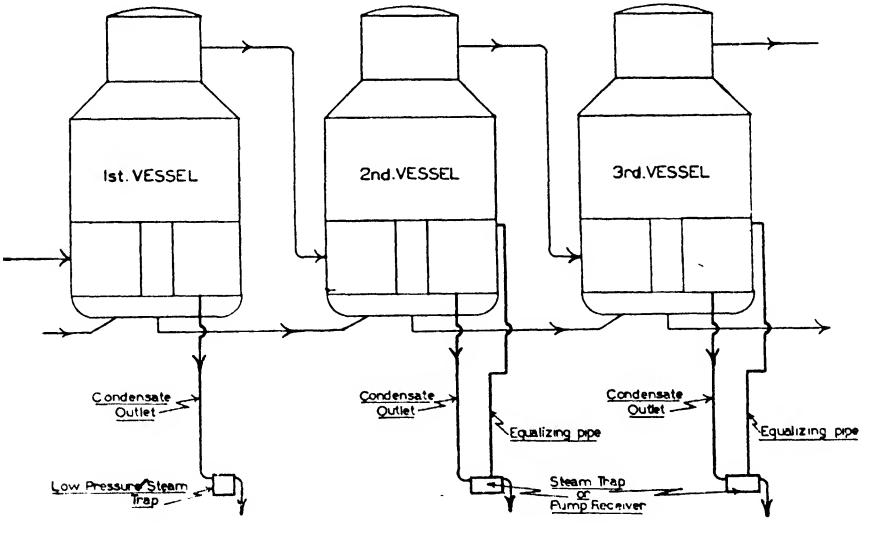
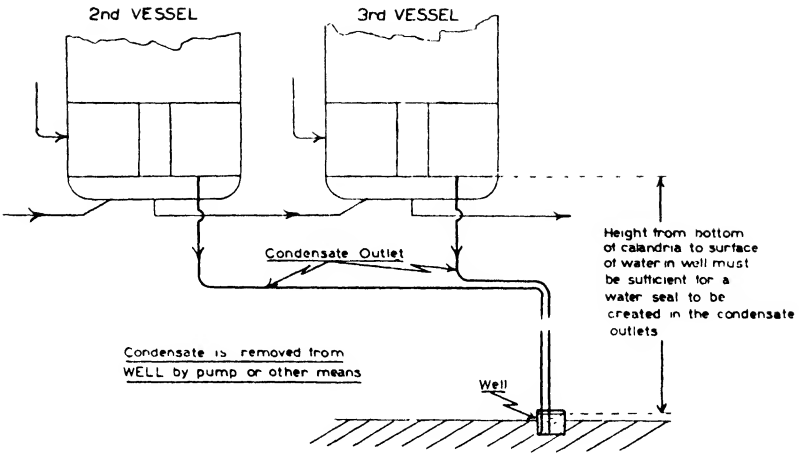
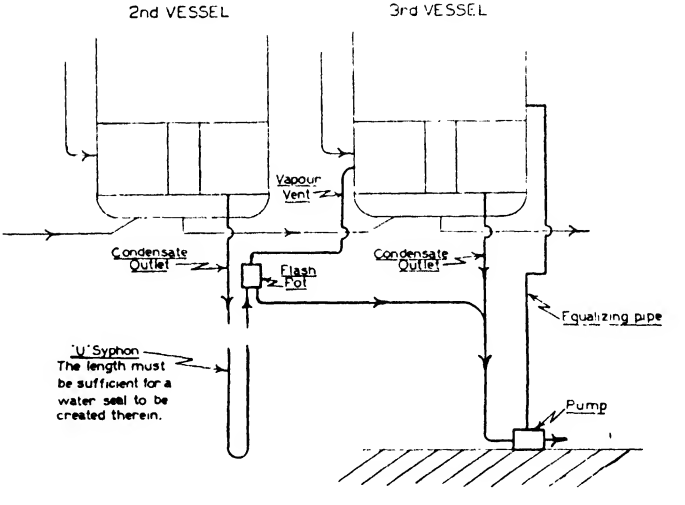


Fig. 13.—Condensate Removal from Evaporator Calandrias.
(*a*) By Trap or Pump.



(*b*) By Barometric Drain.



(*c*) By "U" Syphon.

and that of the open water seal. It is noticed that 4 feet is added as a safety factor to allow for operating fluctuations. Such a height would generally require the construction of a pit in the factory floor below the vessel. This is not the case, however, when the condensate is removed by *"U" Syphons*. It is then passed

from one vessel to the next, going either direct to the calandria or else to an interconnected receiver or flash pot. It is finally exhausted by a suitable pump connected to the calandria of the last vessel. The water-sealed "U" syphons are placed between one vessel and the next. Only the difference in vacua of the two calandrias need then be considered. Assume a second vessel calandria working under 2 in. vacuum and a third vessel calandria working under 10 in. vacuum, the difference in vacuum is 10 — 2 = 8 in., which requires (8 × 1·15) + 4 = 13·2 feet. The "U" syphon is then made 13·2 feet long. The purpose of the U-shape is to ensure a water seal between the two calandrias. The difference in height of the water in each leg of the syphon depends on the difference in vacua. Hence the length of the U syphon is determined so that the water seal is maintained under the fluctuating differences of operation. In a quadruple effect, where the vacuum differences from vessel to vessel are not so great as in a triple effect, the saving in height of platform or depth of pit by the use of "U" syphons is more obvious.

Condensers.

The vapour pipe of the last vessel is connected to a condenser whose function is to condense all condensible vapours issuing therefrom. Condensers are of two types :

(*a*) Surface condensers.
(*b*) Barometric condensers.

Surface condensers are not often used in sugar factory practice. Barometric condensers may be subdivided into parallel current, counter current and ejector. Parallel current and counter current condensers both require an air or vacuum pump to remove the incondensible gases ; an ejector condenser does not, and is therefore simpler. The difference between *parallel current* and *counter current* condensers lies in the relative direction of flow of the cooling water and of the vapours within the condenser body. The most common, perhaps, is the counter current type, in which the vapour enters the lower part of the condenser, and the incondensible gas is drawn off at the top by the vacuum pump. The cooling water is pumped in at the top by a separate inlet and falls by gravity down the body of the condenser. In so doing it

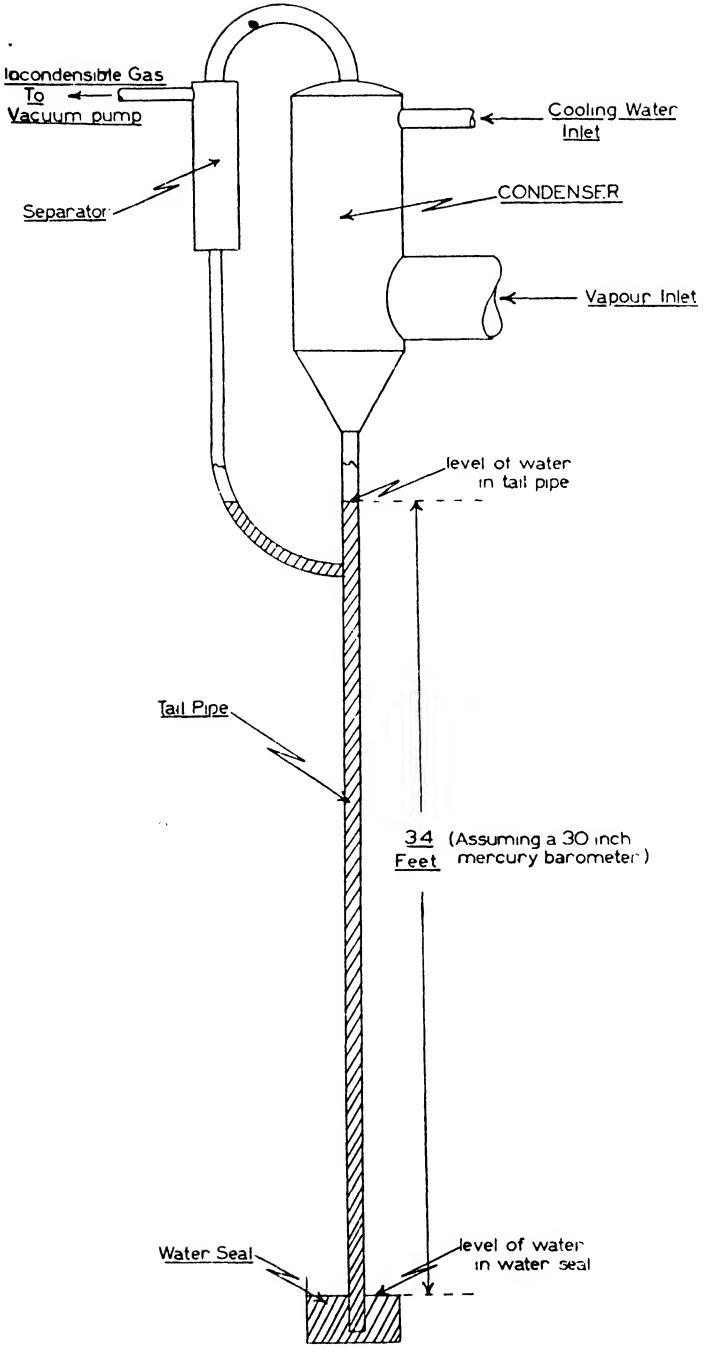


Fig. 14.—Barometric Condenser.

is mixed, by baffles, with the vapours which, on condensing, are carried away with it down the tail pipe. The name "barometric condenser" is used because it must be set at a height of 34 feet or more, so as to form a water barometer in the discharge pipe, tail pipe, or leg (See Figure 14). This is necessary since the condenser is under vacuum. If sufficient height is not allowed, the creation of a vacuum of 26 in. might result in the water rising in the tail pipe to such a height as to flood the condenser and evaporator vessel. In the *ejector condenser*, the vapour enters and is entrained in a series of high pressure jets of water. Both condensible vapour and incondensible gas are thereby removed, but an ample water supply is essential.

The vacuum maintained by a condenser depends, apart from fundamental considerations such as the ability of the air pump to remove all incondensible gas, on sufficient water being supplied at a temperature low enough to produce complete condensation. When the water supply is limited, then a *cooling tower* or *spray pond* must be used. The water discharged from the tail pipe of the condenser is then pumped through the cooling device prior to re-circulation. The temperature to which the water can be cooled is obviously limited by that of the atmosphere. The higher the temperature of the cooled water, the greater the amount that must be used to condense one pound of vapour. The existence of a close-by river of sufficient size obviates the necessity of cooling and removes the possibility of a water shortage.

Air Pumps and Ejectors.

Dry Air Pump (*Vacuum Pump*).

Both surface condensers and barometric condensers of the counter and parallel current types require a dry air pump for the removal of incondensible gas. These pumps are either of the long stroke, low rotative speed, or the short stroke, high rotative speed types. Both operate with very small clearances between the piston and the cylinder. In order to avoid "water hammer," the incondensible gas is freed of drops of water by passing it through a separator. The separator is placed between the condenser and the pump. It is water-sealed in the same way as the tail pipe of the barometric condenser, and in this connection the tail pipe of the separator may be either separate or connected to that of

the condenser. The cylinder of the pump is water-cooled to obtain higher efficiency. Both types are driven by a direct connected steam engine, by an electric motor or other prime mover. An essential point in their operation is the maintenance of air-tight glands and well seated valves. The incondensible gas is exhausted after compression in the pump to a pressure greater than that of the atmosphere.

Wet Air Pump.

This type of pump is now seldom installed because of its high steam consumption. It is of ponderous construction and works at low rotative speeds. It is so called because it removes both the water and the incondensible gas from the tail pipe of the condenser, which is usually placed on top of the pump. No barometric water seal is required, and the vacuum created by the pump is usually sufficient to draw the cooling water into the condenser, thus eliminating the necessity of a water pump. Furthermore, with this type each evaporator or vacuum pan must be equipped with its own unit.

Steam Jet Air Ejector.

The steam jet air ejector embodies the same fundamental points of design as the ejector type condenser. While removal of air is obtained in the condenser by entrainment in jets of water, it is brought about in the steam jet ejector by entrainment in jets of steam. Initially, the designs were expensive on steam, but the modern multi-jet multi-stage ejector shows efficient performance. The advantages are the absence of moving parts and the lightness of construction. An air ejector of this type is used in certain factories as auxiliary equipment to the main reciprocating vacuum pumps.

Scale and Scale Removal.

During the period of evaporator operation, scale or incrustation forms to varying extents on both sides of the calandria tubes. That on the juice side of the tube is invariably the more serious. It is formed because certain of the juice constituents are forced out of solution as water removal proceeds and are thereby deposited on the heating surface. Scaling in the first vessel of an evaporator is seldom so serious as in the last vessel. Its presence

is undesirable because it reduces the rate of heat transmission to a fraction of the amount obtainable with a clean surface. The constituents of the scale vary with the constituents of the juice and the method of clarification. Generally, an analysis shows predominance of silica, sulphate or phosphate. Scale removal may be carried out either mechanically or chemically. *Mechanical removal* involves the use of scrapers either worked manually or rotated by an electric motor. With this method it is difficult to obviate the removal of metal dust from the tubes, with subsequent weakening. A further disadvantage is the necessity for supplying labour during a shut-down period. *Chemical removal* is simpler. The basic idea is to provide a suitable chemical solution which dissolves away or reacts with one or more of the main constituents of the scale, so that it either falls away from the tubes or light brushing only is necessary. Success depends on the choice of the chemical to be used, which in turn depends on the analysis of the scale. For example, the soda ash—hydrochloric acid treatment is used for the removal of sulphate scales. Also, the solution must not be such as to attack the metal of the evaporator vessel. The most efficient technique is to heat the solution and then to circulate it through sprays over the calandria. Thorough washing is essential after the operation is completed.

Removal of scale on the juice side of the tubes is carried out once per week or at other convenient periods. Scale on the steam side of the tubes is generally due to oil suspended in the exhaust steam from the engines. Removal is only necessary at the end of each crop, using one or other of the published techniques, since its effect on evaporator performance is comparatively small.

CHAPTER VII.

Crystallization.

The thick-juice or syrup, after concentration in the multiple effect evaporator, is stored in a series of tanks on the vacuum pan platform for use as required by the pans. In appearance the syrup is a thick, dark brown, fairly viscous liquid, varying from turbid to transparent when viewed in a test tube. For raw sugar manufacture no further clarification treatment is carried out. Syrup contains about 50 per cent. of sucrose by weight. The crystallization of the sucrose is induced by further concentration under the delicately controlled conditions of the single effect vacuum pan. The material, or massecuite, so produced is of a heavy, viscous nature. The operation of first forming the sucrose crystals and then building them up to a more desirable size, is one requiring a skilled knowledge of the fundamental principles involved. Up to recently, "pan boiling" was considered more of an art than a science, and as such the operators would not divulge their closely guarded secrets. Now the factors involved are more widely understood and have been translated into scientific terms. Further, methods and instruments have been perfected which, while still necessitating the presence of the skilled operator, facilitate control of the process and produce a higher recovery of more desirable sugar, which is the ultimate object.

Vacuum Pan Construction.

The outward appearance of a vacuum pan is very much like that of an evaporator vessel. The essential differences lie in a different shape of saucer, different internal arrangements and additional fittings. Since the pan is dealing with a very much more viscous material than the evaporator, designers lay particular emphasis on the *circulation* of the massecuite over the heating surface. The theory of circulation in a pan is the same as that in an evaporator vessel. The boiling material ascends the heating surface and, by displacement, descends the downtake (See Figure 15). An important point of difference, however, is that the heating surface of the pan is often totally submerged to a depth of several

feet. It is difficult therefore to ensure a complete mass movement, free from side tracks and short circuits. Stagnant zones are eliminated as far as possible by careful design. Proper massecuite

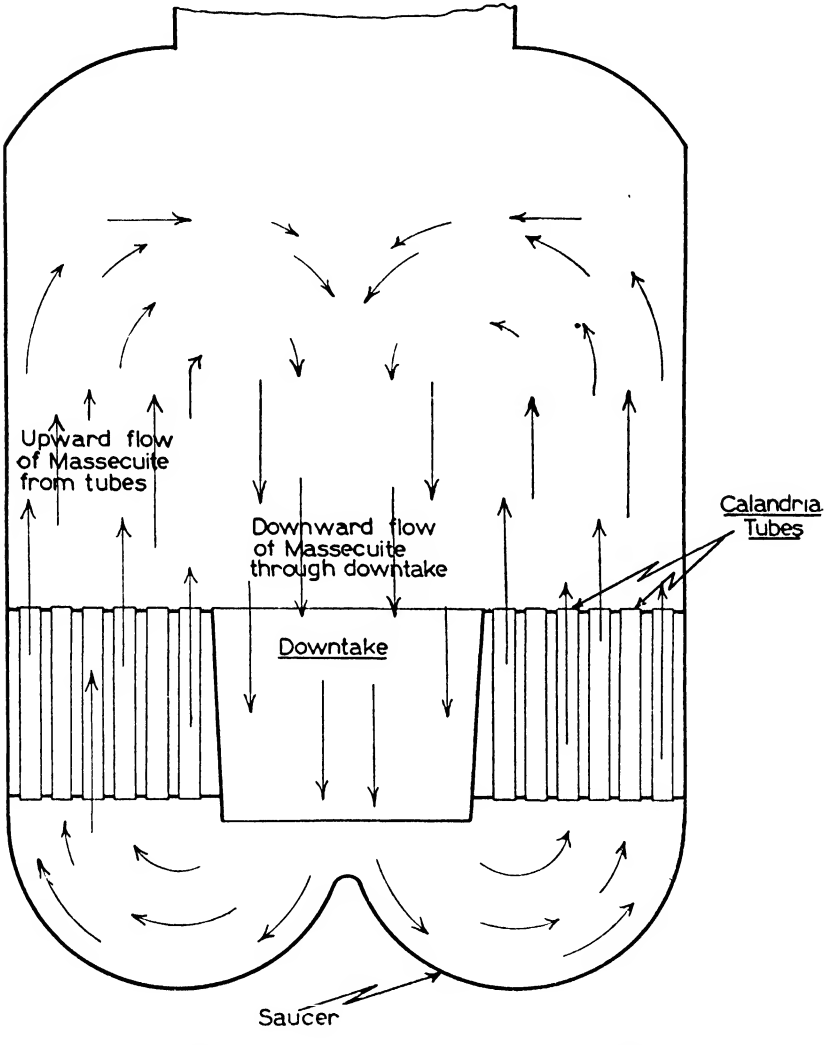


Fig. 15.—Natural Circulation of Boiling Massecuite in a Calandria Vacuum Pan.

circulation results in steam economy, higher sucrose recovery and a more readily saleable product. Its effect on sucrose deposition is discussed later.[1]

[1] Page 86.

Vacuum pans are classified according to the kind of heating surface with which they are fitted. There are two types :—

(*a*) Coil.

(*b*) Calandria.

In the *coil* type pan, the heating surface is made up of copper piping wound in the form of a series of inverted helices. The helices or coils are placed one above the other in such a way that (*a*) there is ample room between the convolutions, and (*b*) there is a central space, or downtake. Both are proportioned so as to promote free circulation. Steam is admitted to the top of each coil separately. There are two valves, one for high pressure steam and the other for back or low pressure steam. Also, arrangements are made for the drainage and removal of condensate from the bottom of each coil. One advantage with this type of heating surface is that it is distributed through the body of the pan more evenly than a calandria. Steam is only admitted to those coils completely covered by the boiling mass. In large pans, where the coils would have to be of excessive length to provide the necessary area of heating surface, they are made in two halves, each with its own steam inlet and condensate outlet arrangements.

The *calandria* type of heating surface is of similar construction to that used in a multiple effect evaporator vessel. An important difference is the increased internal diameter of the tubes to ensure a free flow of the viscous massecuite. Also, the downtake is of larger proportions. In modern practice it may be as much as 50 per cent. of the diameter of the pan, and slightly tapered from top to bottom.

The shape of the *saucer* is governed by considerations of its ability to promote massecuite circulation and to drain the pan free of massecuite when being emptied. It may take the form of an inverted cone having an apical angle of about 90°. With the coil type heating surface, the bottom coil can be wound in such a way that it follows the slope of the saucer, so that no "stagnant zones" are created. The calandria type heating surface offers difficulties in this connection. They can however be overcome by different and more expensive tube plate construction, such as the conical calandria or by the use of a coil below the bottom tube plate. Recently, shallow streamline saucers with

an apical angle of about 140° have been designed and fitted to calandria pans. The centre of the saucer below the downtake is raised and shaped, so that the downward flow of the circulating mass is turned upwards through the calandria tubes (See Figure 15). Again, the basic idea is to eliminate stagnant zones and promote circulation.

The next most important factor in pan design after the placing and the proportioning of the heating surface is the position of the *feed inlet.* As boiling proceeds, further syrup is admitted to the pan but the boiling mass is much thicker and more viscous than the incoming feed. Difficulties are therefore experienced in getting the feed to mix properly. Originally the feed pipe was placed downwards through the downtake, and several minutes sometimes elapsed before the feed "mixed in." Modern designs tend to introduce the feed at a more advantageous point or points such as where the mass is changing its direction of flow from downwards through the downtake to upwards through the heating surface.

The fittings found on a vacuum pan which are not included on an evaporator vessel are a *proof-stick* for withdrawal of a small amount of the boiling material for inspection, *facilities for feeding* syrup, high grade molasses or water as required, a *steaming out connection* for cleaning purposes, a *discharge valve* in the saucer for emptying or "striking" as it is called, and a *vacuum release.* There is also a larger number of sight glasses and the usual thermometer and vacuum gauges.

The use of *mechanical circulators* has recently come into prominence again. The benefits are manifest more especially when boiling the low-grade viscous products, that is, when natural circulation is sluggish. The circulators take the form of a centrally placed shaft to which one or more rotors or propellers are attached. Their object is to force or draw the boiling mass down the downtake. The arrangement has not been used in conjunction with coil type heating surface, only calandria. Another piece of equipment in which circulation is ensured, is a horizontal cylindrically shaped pan, the whole of which rotates except the fixed vapour, steam and feed connections.

Vacuum Pan Arrangement.

It has already been stated that a vacuum pan may be regarded as a single effect evaporator. Steam is admitted to the coils, at 20 to 60 lbs./sq. inch pressure, or to the calandria, at about 5 lbs./sq. inch pressure. The vapour space, under a vacuum of 26 in., is connected directly to the condenser and vacuum pump, which are of the same construction as those described in Chapter VI. In most factories there is more than one vacuum pan. Apart from technical reasons, such an arrangement leads to flexibility in the crystallization process. Also, during the pan cycle, the steam consumption varies over wide limits, and with more than one pan the work can be so arranged that the steam demand on the boilers is fairly constant. Assuming a factory with two vacuum pans (See Figure 16), these can be arranged in any one of the following ways :—

(*i*) Each vacuum pan with its independent condenser and vacuum pump.

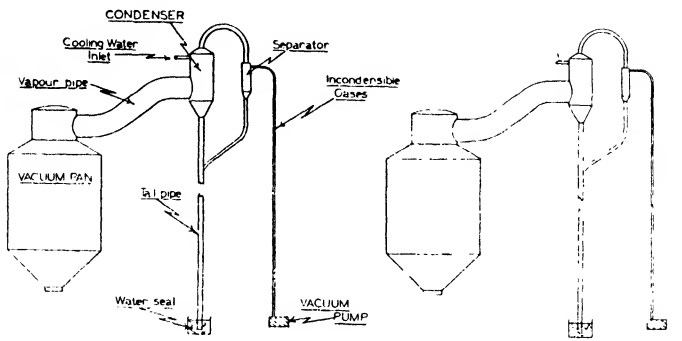
(*ii*) Each vacuum pan with its independent condenser but both connected to the same vacuum pump.

(*iii*) Both vacuum pans connected to the same condenser and vacuum pump.

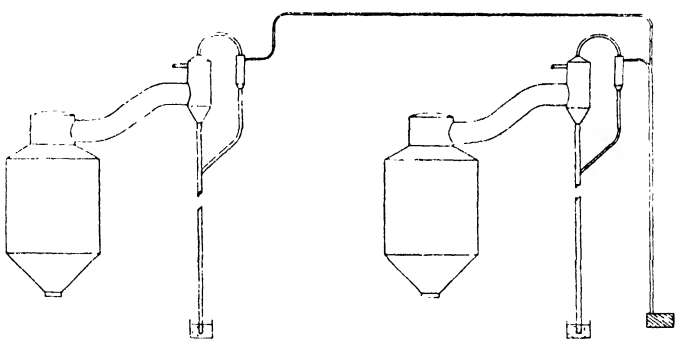
(*iv*) Both vacuum pans and the evaporator connected to the same condenser and vacuum pump.

Where more than one vacuum pan is connected to the same vacuum pump, it is common practice to instal a "booster" circuit. This consists of a small capacity vacuum pump or steam air ejector. Its purpose is to evacuate a vacuum pan after starting but before it is cut-in on the main line, so that there is no sudden drop in vacuum in the units which are already in operation. It must be remembered that absence of fluctuations in vacuum and steam pressure is an essential factor for successful sugar boiling. It is for this reason that each unit should be isolated as much as possible. Controlled variations in the conditions of operation of one unit are then without influence on the other units. From the purely idealistic point of view therefore, arrangement (*i*) outlined above is the most desirable, but considerations of the initial cost of the installation and of other factors must be taken into account.

(i) INDIVIDUAL CONDENSER & VACUUM PUMP



(ii) INDIVIDUAL CONDENSER & COMMON VACUUM PUMP



(iii) COMMON CONDENSER & VACUUM PUMP

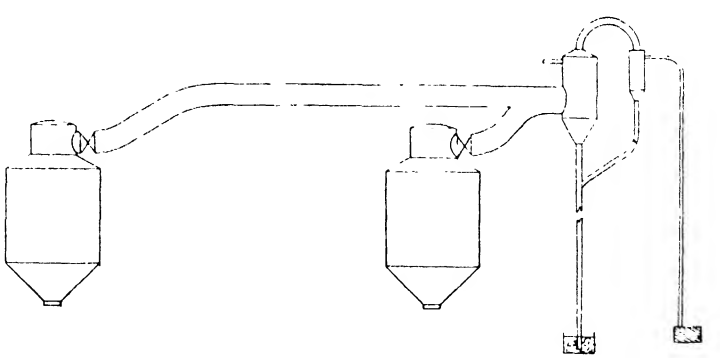


Fig. 16.—Diagram showing different Vacuum Pan Condenser Arrangements.

The vacuum pans are also arranged according to the grade of sugar most usually boiled in each. This is necessary because the different grades of sugar are usually cured or centrifuged in different sets of centrifugal machines. The pans are however interconnected by means of a cut-over pipe, so that massecuite or footing may be transferred from one to the other as required.

The Crystallization of Sucrose from Solution.

Sucrose, in common with other chemical substances, is highly soluble in water, and the solubility increases with rise in temperature. When the temperature and amount of water present are kept constant an aqueous solution of sucrose is in one of three conditions. If more sucrose can be dissolved, the solution is unstable and *undersaturated.* If no more sucrose can be dissolved without the deposition of sucrose crystals, the solution is stable and *saturated.* If so much sucrose has been dissolved that the deposition of sucrose crystals will take place, the solution is unstable and *supersaturated.* A solution may pass from one condition to the next if changes in either the temperature or the amount of water present take place. The direction in which the change of condition occurs depends on whether the temperature is raised or lowered, or whether water is added or removed. In the crystallization of sucrose from cane juice the condition of supersaturation is the one of particular importance. The degree to which the juice is supersaturated is expressed as the *supersaturation coefficient.* It is calculated as the ratio of the sucrose present in the supersaturated juice to the sucrose present in a saturated juice. Two factors must however be constant, (*a*) the temperature, which has been discussed, and (*b*) the amount of impurities present or the Purity (See Chapter XIII) of the juice. Some substances increase the solubility of sucrose while others decrease it. The normal impurities found in cane juice are such that a saturated cane syrup contains less sucrose per unit of water than a saturated solution of pure sucrose. The reverse is true of a saturated beet syrup. The effect of the impurities on the solubility of sucrose is expressed as the *saturation coefficient.* It is the ratio of the sucrose present in a pure saturated solution to the sucrose present in a saturated juice at the same temperature. It varies with the purity. In the factory, the degree of super-

saturation required for the deposition of sucrose crystals from the juice occurs only after the syrup has been further concentrated in the vacuum pan. The necessity for establishing the required degree of supersaturation may be thought of as the creation of a force to overcome the inertia of the sucrose to crystallize in the presence of other substances. Once the crystals are formed, the subsequent task of the pan boiler is to manipulate the operation in such a way that no new crystals appear[1] and none of the existing ones are dissolved. The former state obtains when the degree of supersaturation becomes too great and the latter state when a condition of undersaturation occurs. Instead, the sucrose introduced into the vacuum pan in the feed is made to deposit on the existing crystals so that they grow in size. In terms of supersaturation, this simply means that the supersaturation coefficient is to be maintained at a value such that the above requirement is brought about. The value required varies according to the amount of impurities present, that is, according to the grade or purity of the massecuite being boiled. The scientific outlook on pan boiling is therefore expressed in terms of solubilities. The practical operator interprets varying solubilities in terms of "look" and "feel" of the sugar, since supersaturation is closely related to viscosity.

Vacuum Pan Operation.

Sugar Boiling is carried out under conditions of vacuum similar to those in the last vessel of a multiple effect evaporator. The process is not continuous but performed in batches. A charge of syrup is drawn into the pan and steam turned on in the coil or calandria so that evaporation proceeds. Eventually, withdrawal of a proof by the proofstick shows the presence of minute crystals. When sufficient of these have been formed, a further charge of syrup is introduced so that the supersaturation coefficient is lowered and crystal formation stops. From this point onwards, syrup is continuously or intermittently fed to the boiling mass, so that as the pan fills up the crystals grow in size. When the pan is full, no further feed is admitted and the massecuite is prepared for "striking." A massecuite is therefore a mixture of

[1] The appearance of a secondary granulation, or large numbers of minute sucrose crystals, during the boiling of a pan of sugar is known as "smear" or "false grain." It is brought about by inherent causes, such as bad pan design or inadequate circulation, or by inattention on the part of the operator.

sucrose crystals and the remainder of the syrup which is then called "molasses" or "mother liquor." Striking is carried out by turning off the steam, breaking the vacuum and opening the discharge valve in the saucer. The massecuite is struck or emptied into a strike receiver, mixer or crystallizer.

Graining or Crystal Formation.

The actual formation of sucrose crystals within the syrup can be brought about by several methods, provided the required degree of supersaturation has first been attained. An outline of the commonest of these methods is as follows :—

The Waiting Method.

By this method, the pan is operated under the normal conditions of vacuum and temperature. A graining charge is introduced which varies in extent but which is usually one-third to one-quarter of the total pan capacity. A limiting factor is that at least one coil or all the calandria must be completely covered when the volume of the charge is at its smallest. Evaporation takes place in the usual way, and eventually the sucrose crystallizes by virtue of the continued removal of water after the required supersaturation has been attained. The requisite number of crystals is usually not obtained for half an hour to an hour after the appearance of the first batch. Hence the crystals are irregular in size and the process is time-consuming. The irregularity is a safety factor for the operator, because he can stop crystal formation later than essentially necessary and then dissolve out the small crystals later on with water when he is better able to judge the exact requirements.

The Shock Method.

The preliminary concentration is carried out at a lower vacuum, that is a higher temperature than normal. When the supersaturation coefficient attains a certain value, the vacuum is increased so that the boiling temperature is thereby lowered and the supersaturation coefficient increased. Crystallization then takes place spontaneously. It is stopped with a syrup charge as in the previous method. The resulting crystals are regular in size. A similar result may be obtained by the introduction at the correct time of a charge of syrup or clarified juice.

The Seeding Method.

Preliminary concentration takes place under the normal conditions of vacuum and temperature. At a predetermined supersaturation, a small amount of finely ground white sugar is introduced into the boiling mass. This has the effect of seeding or of inducing the sucrose to crystallize.[1] It is stopped when required as in the previous methods, and the resulting crystals are regular in size.

Boiling Schemes.

The ultimate object of all pan boiling schemes is the recovery of as much sucrose as possible in the crystalline state. It is usually carried out in two or more stages, because it is impracticable to exhaust the syrup of its crystallizable sucrose in one operation. This leads to the boiling of a series of graded massecuites, the first of which is produced by the boiling of pure syrup only (called an "A" massecuite). The second is boiled partly of syrup and partly of the mother-liquor ("A" molasses) derived from the first. It is called a "B" massecuite. Similarly a "C" massecuite is composed of a small proportion of syrup and then "B" molasses. This terminology may be more clearly understood by reference to the table herewith and Figure 17 :—

Table VI.

Grade.	Composition.	Products
"A" massecuite	Syrup only	"A" sugar & "A" molasses.
"B" massecuite	Syrup & "A" molasses	"B" sugar & "B" molasses.
"C" massecuite Low-grade massecuite Java massecuite	Syrup & "B" mols.	"C" sugar, Low-grade sugar or Java sugar and "C" molasses or Final molasses.

The relative proportions of syrup and of "A" or "B" molasses used for the production of a "B" or "C" massecuite depend on the relative purities (See Chapter XIII). The aim is to produce a series of "B" and of "C" massecuites of fairly constant purities which are fixed by previous experience of the conditions. The purity of the "A" massecuite is the same as the purity of the syrup, which fluctuates with that of the incoming juice. Usually the purities of the "B" and "C" massecuites are about 72 and 56

[1] The classic example of this phenomenon is the introduction of a small crystal into a supersaturated solution of ordinary photographer's "hypo." The hypo then crystallizes immediately.

respectively. The actual organization of the boiling programme varies from one factory to the next, and no specific set of conditions can be laid down. The main features to bear in mind are that the "A" and "B" sugars are bagged and shipped as 96° Raw, hence

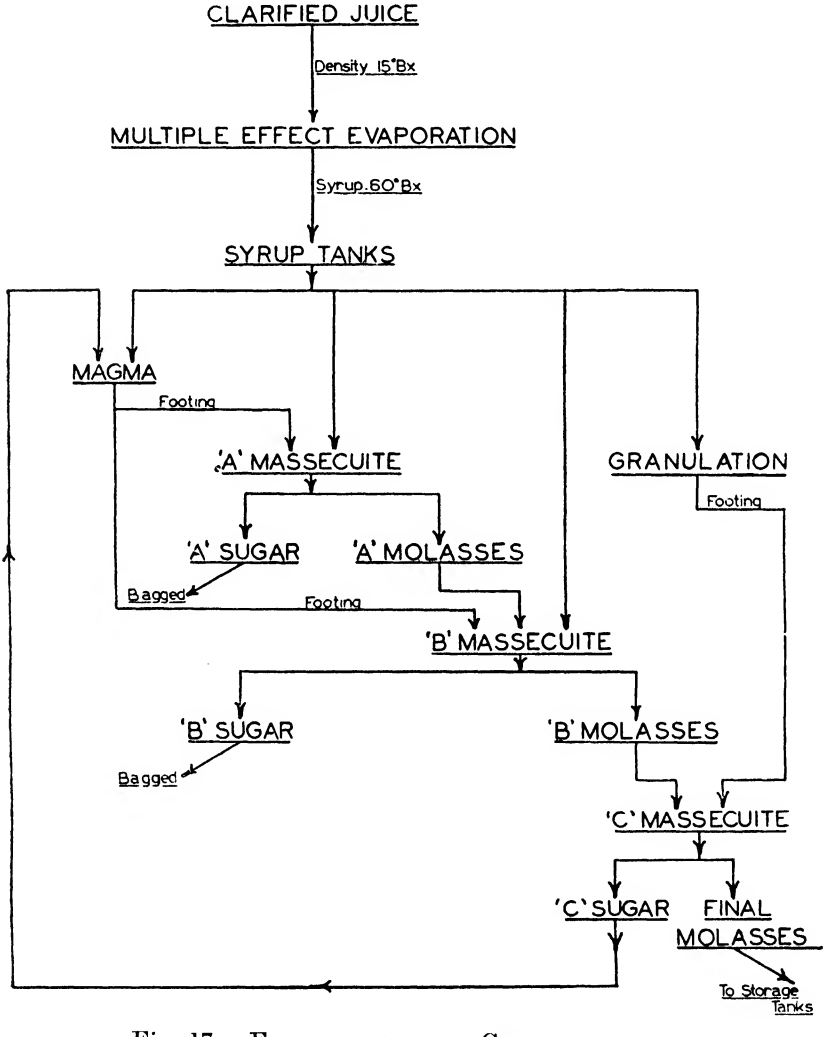


Fig. 17.—Evaporation and Crystallization.

they must analyse about that polarization (See Chapter XIII), and that the Final Molasses must be exhausted. In some cases, only "A" and "B" massecuites are boiled. In others, "A", "B", "C" and "D", that is four stages are necessary to bring about the

necessary degree of exhaustion. Sometimes, "C" sugar is bagged and sold, but it is usually used as footing for the "A" and "B" massecuites.

Footings (Pied-de-Cuite).

Graining is a time and steam consuming process. Furthermore, "C" massecuites require to be boiled on a smaller and more numerous grain, or crystal, than the "A" or "B". Hence instead of forming one type of grain for the former and another for the latter, the "C" sugar is used as a footing for the "A" and "B" massecuites. In this method, the low polarizing "C" sugar is mixed with syrup to form what is known as a Magma. The magma is taken into the vacuum pan and the massecuite boiled on it instead of on newly-formed crystals. Newly-formed crystals, or a granulation, must however still be used for the boiling of the "C" sugar itself. One granulation will provide enough footing for two to six "C" strikes. It therefore eventually makes a considerable amount of "A" and "B" sugar, which will consist of a more or less standardized size of crystal. Before the use of "C" sugar as a footing became general, it was the practice to mix it after suitable treatment with the "A" and "B" sugars.

String-proof Boiling.

In the above discussion it is assumed that the "B" molasses is "boiled to grain," that is, that crystals are present in the vacuum pan when the "B" molasses is boiled on the "C" massecuite. Prior to the perfection of the technique of this operation, string-proof boiling was practised. "B" molasses is taken into the pan and concentrated until the pan is full. No crystals are either present or allowed to appear. Evaporation proceeds until the "string" test can be carried out. The density is then about 91° Brix. It may be measured with the refractometer (See Chapter XIII). The pan is then emptied into large concrete or stone cooling tanks, and crystallization takes place due to the fall in temperature. The recovery of sugar is not so great as the "boiling to grain" or "Java" process but string-proof boiling is still used occasionally for convenience at the end of crop.

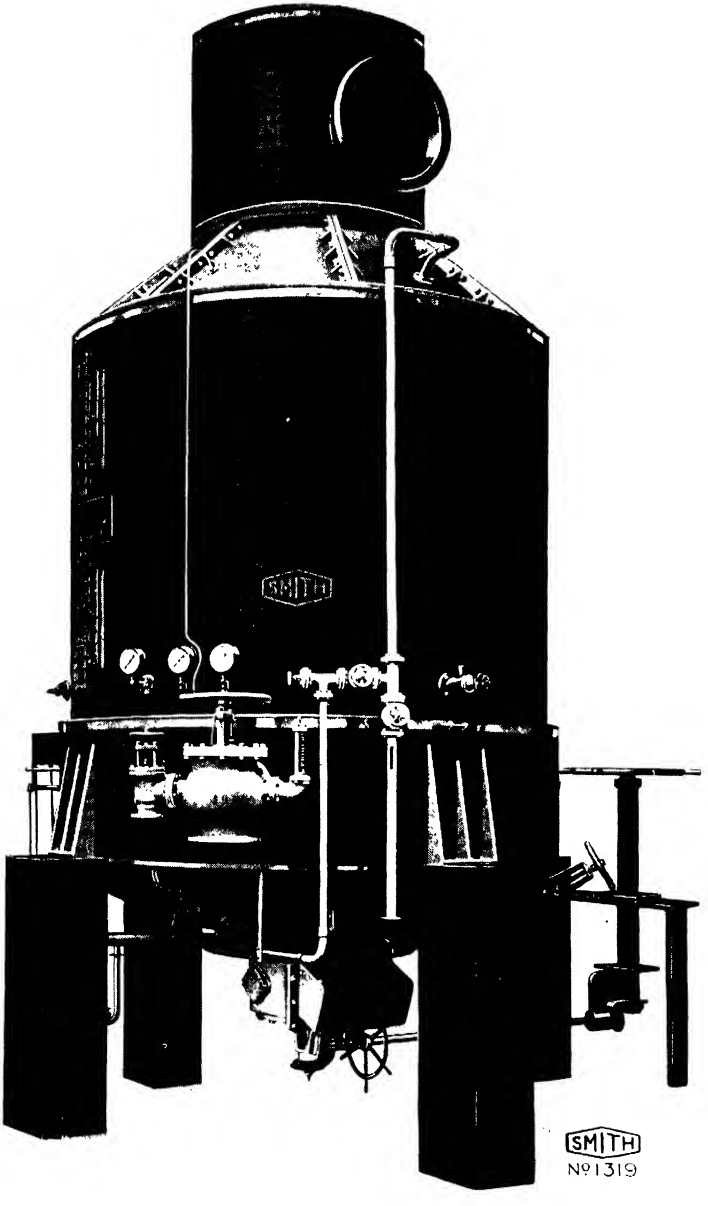
The Boiling of Low-Grade, or Java, Massecuites.

In raw sugar manufacture, the boiling and subsequent treatment of the low-grade "C" massecuites are, comparatively, the

most important steps in the Crystallization process. For this reason they have always, and especially recently, been the subject of a great deal of research. The object is not far to seek. The Low-grade work is the last chance, so to speak, that the factory has of recovering sucrose before the residue or final molasses are pumped out of the factory for sale or for alcohol manufacture. Furthermore, the massecuite is of an inherently viscous nature and due to this and other factors, special care must be taken in its treatment.

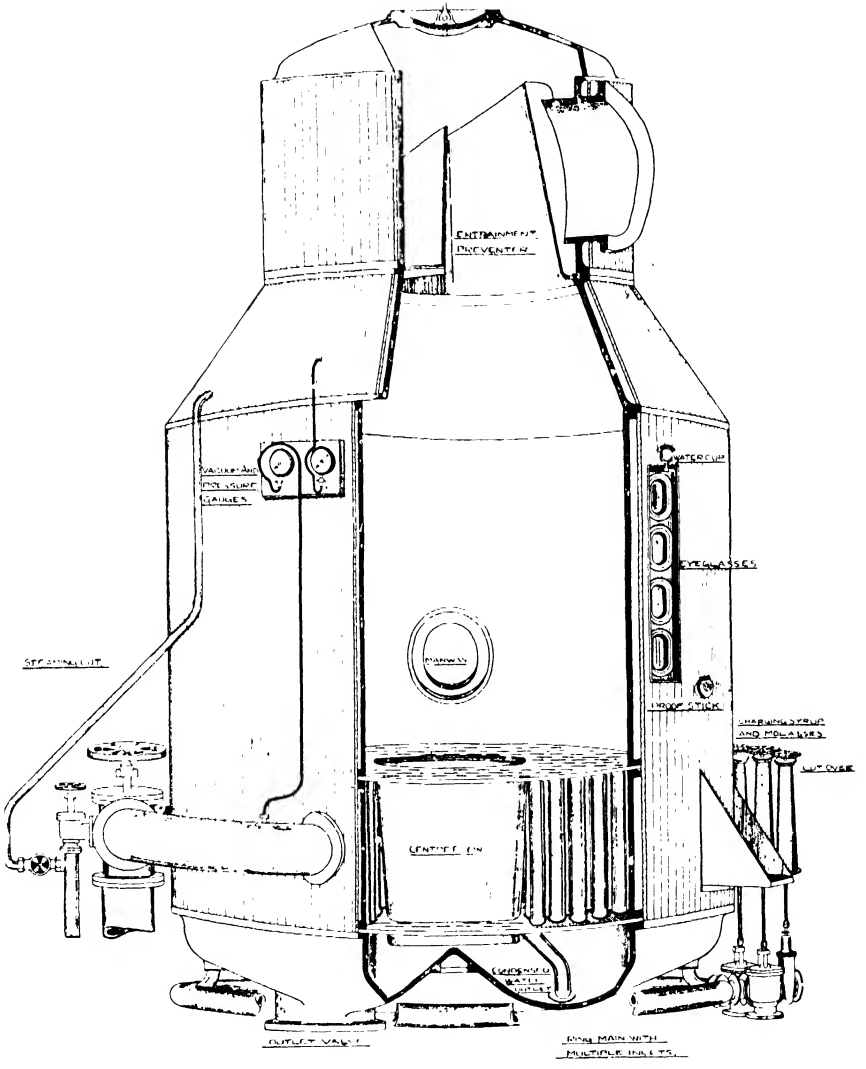
Type of Footing.—It has been stated above that the footing for low-grade massecuites should consist of numerous small crystals. This type of footing is necessary because, weight for weight, small crystals offer more surface area than large ones. The surface area is important because the deposition of sucrose takes place thereon. The mechanism of sucrose deposition on the existing crystals may be regarded as follows. Each sucrose crystal is suspended in a small zone of mother-liquor. Each small zone contains sucrose in supersaturated solution. On the immediate surface of the crystal the sucrose has very little distance to diffuse to be deposited. When deposition has taken place, there is a fall in concentration of sucrose in solution in the immediate vicinity of the crystal. Further diffusion tends to re-establish the concentration balance by sucrose migration from the outer layers of the zone. Hence the smaller the zone or the greater the number of crystals and the greater the surface area offered for deposition, the more thorough will be the crystallization.

Circulation.—The value of efficient circulation follows logically. When the crystals are constantly changing their positions in the boiling mass the relatively unexhausted zones are being brought in contact with new crystal faces. Slow boiling introduces a time factor of equal value. Time of boiling can be reduced by the use of mechanical circulators, or by special types of pan design which promote circulation. The nett result is the same. In low-grade boiling, the situation is aggravated because of the relatively high proportion of impurities present. These not only increase the viscosity, which reduces the ability of the massecuite to circulate, but also increase the inertia of the sucrose to crystallize. Fast boiling of low-grade massecuites on unsuitable footings is therefore a false economy. An appreciable amount of sucrose which could be



Modern Type of Vacuum Pan

(*A. & W. Smith & Co. Ltd.*)



SECTIONAL DRAWING OF A CALANDRIA VACUUM PAN.
(John McNeil & Co. Ltd.)

recovered in the crystalline form is then held in solution and therefore lost in the final molasses. Most of it does, however, eventually crystallize as fine grain, and settles to the bottom of the molasses tank.

Temperature and concentration.—Since the solubility of sucrose decreases with fall in temperature, the lower the temperature at which the pan is boiled, the greater will be the crystallization. Also the final result will be influenced by the degree to which the massecuite is concentrated prior to striking. The higher the concentration, that is the more water that is removed, the less the amount of sucrose which is able to remain in solution. A limiting factor in this connection is the fluidity of the resulting massecuite.

The massecuite is struck at a temperature which varies between 150°F. and 165°F. This is about 80°F. above the ordinary temperature of a tropical factory. Hence if suitable arrangements are made so that the massecuite, after boiling is complete, cools to about factory temperature, further sucrose will deposit on the existing crystals. Such a treatment is known as crystallization-in-motion and takes place in crystallizers.

Crystallization-in-Motion.

The need for maintaining the massecuite in motion during the period of cooling is exactly the same as the need for efficient circulation in the vacuum pan, that is, fresh zones of mother-liquor are constantly being brought in contact with the crystals. It is accomplished by the use of mechanically driven paddles. Cooling takes place by heat transfer from the hot massecuite either to the surrounding air (Air Cooling) or to cold water pumped through a series of coils or elements (Water Cooling).

Crystallizer Construction.

A crystallizer consists of a horizontal cylindrical or "U" shaped tank. There is a centrally placed shaft to which are attached a series of stirring paddles or a spiral ribbon. It is driven through gearing by an electric motor, steam engine or other suitable means. For water cooling, there are various types of equipment available which differ both in principle and construction. Most crystallizers are designed to be of such capacity

as to hold one full pan strike. Continuous units are however available into which hot massecuite is pumped at one end and from which cooled massecuite is constantly withdrawn from the other.

Crystallizer Operation.

An important factor in crystallizer operation is the rate of cooling. It must take place so that the massecuite is not cooled so rapidly that the sucrose forced out of solution forms new crystals, and not so slowly that the pans are kept waiting. Under ordinary conditions, cooled massecuite discharged from the crystallizer at 90°F. shows good average work. With water-cooled crystallizers the time taken for cooling is less than for air-cooled crystallizers, unless special arrangements are made for bringing the air into close contact with the massecuite. Less crystallizer capacity, with its resulting savings, is therefore required with this type of equipment.

Vacuum Pan Crystallizers.

Recently, a new type of equipment has been designed in which both the boiling and the cooling of the "C" massecuite takes place. Of the two existing kinds, one was derived from a crystallizer and the other from an ordinary calandria vacuum pan. After boiling is completed, the pan is not emptied until the massecuite has been subjected to the cooling cycle. An obvious saving with such equipment is the elimination of crystallizers, so that the low-grade crystallization section of the factory becomes very much more compact. In both kinds, power is required to create efficient circulation of the massecuite within the unit during both the boiling and the cooling cycles.

Scientific Pan Control Instruments.

The scientific instruments designed to assist the pan boiling process aim at indicating, directly or indirectly, the degree of supersaturation which exists in the mother liquor, or molasses. The method used varies with the different types, of which the commonest, in their simplest forms, are as follows :—

The Industrial Refractometer.

The industrial refractometer is attached to the side of the pan in place of one of the sight glasses. A small quantity of the

boiling massecuite is admitted to the instrument, and the refraction of the mother liquor is measured in terms of degrees Brix density (See Chapter XIII). By comparison with suitable tables, it is seen whether the rate of feed to the pan should be increased, decreased or kept constant.

Boiling Point Elevation Measurements. (Smith's "Micromax").

In the discussion on Evaporation it was stated that substances in solution bring about an elevation of the boiling point. The magnitude of the elevation is proportional to the concentration of the substances. This phenomenon is made use of in this instrument. A small container in which water is boiled is connected to the vapour pipe of the pan, hence the conditions of pressure, or vacuum, in the container and in the body of the vacuum pan are the same. One thermometer is immersed in the boiling massecuite in the pan and another in the boiling water in the container. The difference in temperature recorded by the two thermometers, that is the boiling point elevation, is indicated by a needle and recorded on a chart. The pan operator's task is to maintain the needle as near to a predetermined line on the chart as possible by suitable manipulation of the feed valves, etc.

Electrical Conductivity Measurements. ("Cuitometer," "Panometer," etc.).

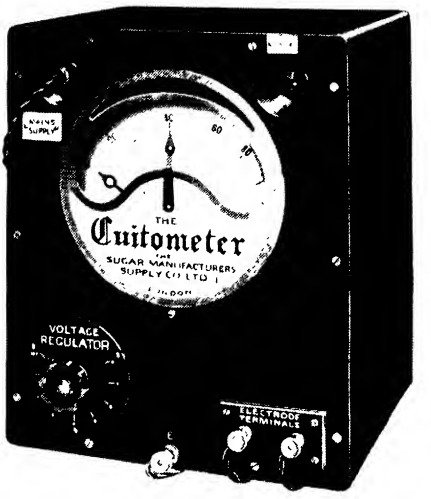
Cane juice has the power to conduct electricity. When a pair of electrodes are immersed in a juice, syrup or massecuite, the flow of current is influenced by viscosity, temperature, ash content and, in the case of a massecuite, crystal content. Of these factors, viscosity is dominant to such an extent in a massecuite that the others can be ignored. Viscosity, in turn, varies with supersaturation. When the current flowing between the pair of electrodes is measured, it is seen to decrease with a rise in viscosity and in supersaturation. The outfit consists essentially of a pair of electrodes placed in the side of the pan. They are connected through a source of A.C. current to a dial or recording milli-

amperemeter. The method of use is the same as that described above for the Micromax.

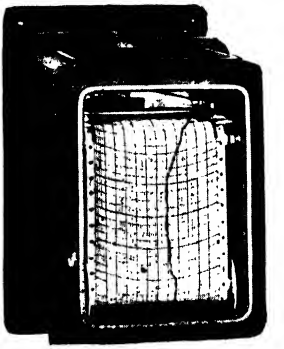
The instruments should, generally speaking, be looked upon as an aid to the operator in the same way that a mariner regards his compass. In this light, therefore, they provide a definite step forward in crystallization technique. They indicate by a definite reading a specific condition of the boiling massecuite. All three types however require either a set of readings from a previous boiling conducted by an expert or the calculation of tables which show the desired readings under a given set of conditions. The crystallization process is therefore not yet completely free from the influence of the expert sugar boiler.

Final Molasses.

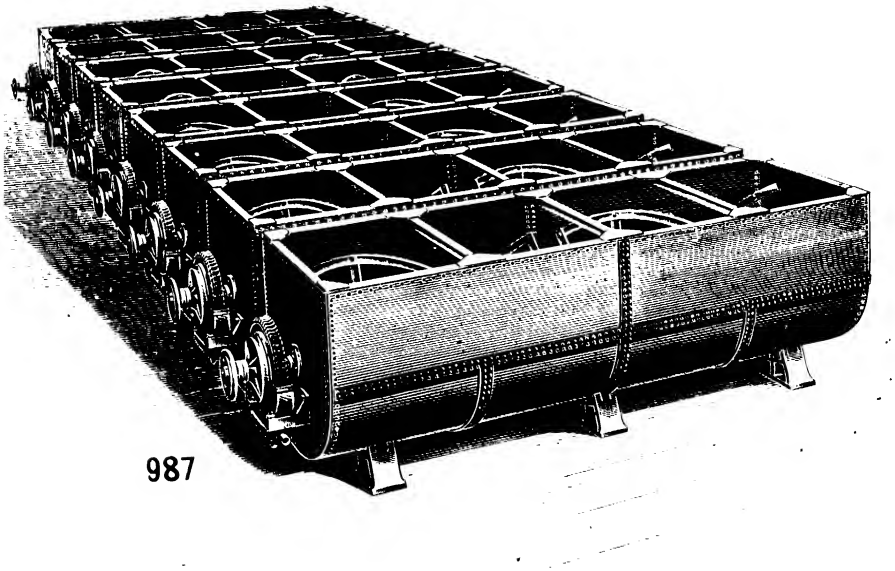
Whatever type of sugar is made from sugar cane juice, and whatever process is used in the manufacture, Final Molasses must always be a by-product of the factory. It is the mother-liquor or molasses from the lowest grade massecuite (See Table VI). It contains the sucrose which has not been recovered in the crystal sugar, the non-sucrose either added or originally present in the juice which has not been precipitated or destroyed in the manufacturing process, and the water not removed by evaporation. Final molasses is a dark-coloured, viscous, bitter tasting liquid, known also as "Blackstrap." It retains in solution from 4 to 12 per cent. of the sucrose in the original cane, and, as such, is one of the major sucrose losses to be accounted for by chemical control of the factory. It is natural therefore that extensive research should have been carried out to find the reason why two apparently exhausted molasses, for example, should contain different amounts of sucrose. Factory control recognizes that all the sucrose in the cane is not "available," that is, it cannot all be crystallized and recovered. It is also known that certain factors influence the degree of recovery, but it is not yet possible to analyse a juice and to forecast by calculation the analysis of a fully exhausted molasses derived therefrom.



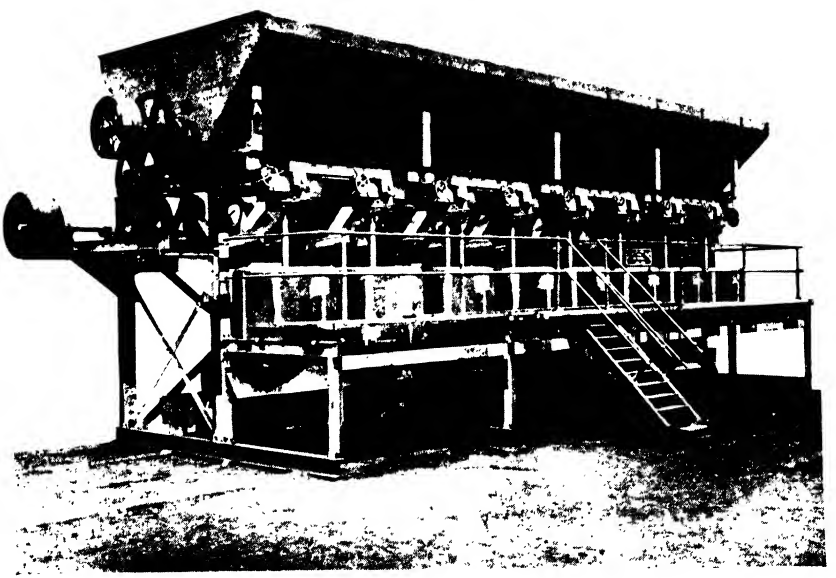
CUITOMETER INDICATOR.
(Sugar Manufacturers' Supply Co. Ltd.)



CUITOMETER RECORDER.
(Sugar Manufacturers' Supply Co. Ltd.)



Air-Cooled Crystallizers (Open Type)
(*Watson, Laidlaw & Co. Ltd.*)



Battery of Eight Belt-Driven Centrifugals.
(*Pott, Cassels & Williamson*)

CHAPTER VIII.

Separation.

Massecuite from the vacuum pan or crystallizer is a mixture of sucrose crystals and molasses. The next step in the process is their separation. Before centrifugals came into use, separation or curing was accomplished by placing the massecuite in wooden barrels having perforated bottoms. The barrels were placed on racks over a gutter, into which the molasses drained by gravity. Separation comparable with centrifuged sugar was never obtainable and the process was exceedingly slow. It could be hastened somewhat by forcing compressed air into the top of the barrel or by creating a vacuum underneath. The centrifugal accomplishes the same task in as many minutes as the drainage process took weeks. The reason for this is that a force many times greater than that of gravity is developed by centrifugal action. The machine is so arranged that when in motion, the molasses is thrown off and the sugar crystals retained. The modern machine has gradually been developed from cruder types. It consists essentially of a perforated metal drum or basket attached to the lower end of a vertical spindle and driven at a high rotative speed by suitable means. In the first designs, the spindle was supported at the top and bottom by a bearing. If the machine was in any way out of balance due to uneven loading, vibration was set up which in certain cases tore away the bearings.

The present day machine is derived from BESSEMER'S patent. This provides for suspension of the spindle from the top so that during operation the basket can find its own centre of oscillation. It is an essential feature of all modern designs. WESTON accomplished the suspension by using a hollow rotating spindle to which the basket was attached, supported internally by a solid stationary one. His method of overcoming the problem of suspension is not now utilized by all makers, because of the advent of adequate ball or roller bearings which allow of the use of a single solid spindle.

Centrifugal Construction.

The perforated shell or basket is attached to the lower end of the rotating spindle. The spindle is suspended from a rubber buffer, which is in turn supported by the girder framework. The basket is made of steel and three to five steel hoops are shrunk on to prevent it bursting under the action of the centrifugal force. Also, it is partly closed at the top by a lip, and the discharge hole in the bottom is covered by a drop valve. The basket rotates within a monitor case or curbing, which serves to collect the separated molasses and to discharge them through a spout into a gutter. Two screens are placed inside the basket, a coarse one of about ¼ in. mesh and then one of finer mesh. The fine mesh screen retains the sugar crystals within the basket but allows the molasses to flow through. The coarse mesh one ensures free drainage for the molasses under operating conditions. The massecuite is charged into the basket through the open top. As the machine begins to rotate and centrifugal force is developed, the massecuite climbs the vertical sides and is restrained from overflowing by the lip. The molasses drains away through the sugar crystals and is expelled from the machine. When the machine is stopped, the dried sugar is found as a vertical wall round the inside of the screen.

Method of Drive.

The centrifugal is driven by one of three methods :—

(*a*) Belt.
(*b*) Individual electric motor.
(*c*) Individual water turbine.

In *Belt* drive, power, derived from a steam, oil or gas engine, or an electric motor, is transmitted through belts by an arrangement of pulleys. Since the speed of rotation of the prime mover is generally less than that of the centrifugal machine, an intermediate or counter shaft is used so that the correct rotative speed ratios may be obtained. Such a shaft has two further purposes when several machines are driven by one engine : (*a*) It distributes the power to all the centrifugal machines in the battery, and (*b*) it allows the use of a separate clutch to each machine for individual starting and stopping. With the batch method of drive, the power of the prime mover need not be such as to cover the total maximum power demand of all the machines connected to it.

The maximum power demand of a centrifugal machine occurs during the period of starting and accelerating. Once the optimum speed has been attained, the power demand is very much less. Hence by arranging that one machine starts at a time, the power of the prime mover need only be enough to cover this, together with a reserve sufficient to keep the others running. The chief operating expense is the maintenance of the belts and clutches.

When each machine is equipped with an *individual electric motor*, the power of each motor must be sufficient to overcome the period of starting and acceleration. Thus the total power installed in the battery is more than with belt drive. Opposed to this, there are no belts or shafts to be maintained, and the failure of one motor does not shut down the whole station.

Similarly, the *individual water turbine* has much in common with the individual electric motor. Special arrangements are usually made to provide more power for the starting period. The power is initially derived from a high pressure water pump.

The method of drive to be installed depends on the initial cost of the installation, the cost of maintenance and of operation, and other purely local circumstances connected with the particular factory.

Speed of Rotation.

The standard speed of rotation of a centrifugal machine depends on the machine's diameter. It is such that the same centrifugal force is created at its periphery as at the periphery of a 30 in. diameter basket revolving at 1200 r.p.m. Recently, designs have been perfected whereby the rotative speed has been very much increased over and above the old standards. Such *high gravity factor machines* are used principally on low-grade masse-cuites in which the molasses to be separated are very highly viscous. The result is a more thorough separation and a shorter time of cycle. The higher speeds of rotation should not be used unless the machine is especially designed for operation under those conditions.

Cycle of Operation.

The cycle of operation of a centrifugal machine consists of : (*i*) Charging ; (*ii*) Accelerating ; (*iii*) Running at full speed ;

(*iv*) Stopping ; and (*v*) Discharging. Under certain conditions charging and accelerating may occur together. With high grade fast curing sugars, running at full speed assumes a relatively small proportion of the total cycle time, hence the efficiency of operation depends largely on the rate of acceleration and the rate of stopping. The reverse is true with low grade, slow curing sugars. It is for this reason that the modern high gravity factor machines are so well suited to this duty. The complete cycle time may vary from 3 minutes in the former case to as long as 35 minutes in the latter case.

Curing High Grade Sugars.

High grade sugars derived from "A" and "B" massecuites are usually centrifuged or cured within twelve hours of striking from the vacuum pan. During the interim, the massecuites must be kept gently stirred in a crystallizer or mixer. The mixer acts as a receiver from which the centrifugals are charged. In certain cases, washing may be necessary to obtain a required colour or polarization. This is carried out by spraying water on to the inside of the sugar layer after most of the molasses has been separated. The practice is general. It should not however be carried out unless absolutely essential, because dilution of the molasses film round the sugar crystal creates conditions suitable for deterioration (See Sugar Deterioration). When centrifuging is complete, the sugar is emptied from the basket. The discharge valve is opened and the wall of sugar is cut down with a wooden or steel spade-like instrument or a mechanically operated plough.

Curing Low Grade Sugars.

Low grade sugars are cured after cooling in the crystallizer. The curing process is similar to but slower than that of the high grade sugars. Washing should never be permitted, because sugar is dissolved from the crystals and mixed with the Final Molasses.

Warming Low Grade Massecuites.

Provided the crystal size and characteristics are such that molasses drainage can take place in the centrifugal, the rate of drainage under any given set of conditions is governed by the viscosity of the molasses. When the work required of the low

grade sugar centrifugal station is more than its normal capacity, the effect of the viscosity factor may be reduced by one of two methods : (*i*) Dilution, or (*ii*) Warming. Special care is required with either process since sucrose may be dissolved from the crystal faces unless certain specified conditions are observed. The reduction of the viscosity by the addition of water is extremely difficult to control and to perform if sucrose solution is to be avoided. The reason for this is the difficulty of incorporating water with the heavy viscous molasses of the massecuite so that local over-dilution does not occur. Alternately, warming or heating is relatively simple. The limiting factor is the highest temperature to which warming can be carried. Every molasses has a characteristic *Saturation Temperature.* The saturation temperature is the temperature at which the molasses is saturated with respect to sucrose and above which it will dissolve sucrose. Provided, therefore, that this temperature is not exceeded, a material reduction in viscosity is obtained without the loss of any sucrose by dissolution. Recent work indicates that the viscosity is halved for each 10°F. increase in temperature. Nearly all low grade massecuites are capable of being warmed 10°F. to 20°F. before the saturation temperature is attained. Hence it is practicable at least to halve the viscosity by this method. In practice, warming is carried out by pumping water at a suitable temperature through a warming element, such as a coil or tubes, situated in the crystallizer, gutter or mixer. It is obvious that since warming is carried out to facilitate curing, the maximum permissible temperature should be maintained until the massecuite is charged into the centrifugal machine. Modern practice therefore favours warming in the mixer situated immediately above the centrifugals. Preliminary warming may however be carried out in the gutter between the crystallizer and the mixer. When warming is carried out in the crystallizer by circulating warm water through the cooling coils, there is ample time for loss of temperature before the massecuite is charged into the machine, and the effect is therefore reduced. The use of steam as the heating agent is not in accordance with modern ideas because of the large temperature difference between it and the massecuite, and of the inability to prevent severe local overheating with the resultant solution of sucrose.

Reduction of viscosity of the molasses is best obtained, therefore, by warming rather than by dilution. Warming is carried out in the mixer by the circulation of water of suitable temperature through coils or tubes. From the point of view of safety in preventing the solution of sucrose, the inlet temperature of the warming water should not be higher than the saturation temperature of the molasses to be warmed. Also, arrangements should be such that the applied heat is evenly distributed throughout the masse-cuite.

Sugar Conveyors.

The sugar is discharged from the centrifugal into a tray or conveyor situated underneath. It is conveyed to the sugar bunk for bagging. The conveyor may be one of three types : (*i*) Screw or Ribbon, (*ii*) Belt or Slat, and (*iii*) Grasshopper. The names are self-explanatory, except perhaps the grasshopper which consists of a sheet iron tray supported on sprung legs. One end of the tray is connected to an eccentric, which when rotated imparts a forwards and backwards shaking movement. The conveyor discharges the sugar into a bucket elevator which, in turn, discharges into the bunk.

Sugar Bagging.

One or more inverted pyramid-shaped hoppers are usually inserted into the floor of the bunk. The bag is strapped round the mouth of the hopper, and sugar allowed to flow into it by manipulation of a suitable gate. The size of the bag varies from 20 to the ton to 8 to the ton. The mouth is closed by manual or machine sewing.

Sugar Deterioration.

Nearly all sugars deteriorate between the time of manufacture and the time of sale. Deterioration is brought about by the action of moulds, bacteria and yeasts which attack sucrose and produce decomposition products. The extent to which it occurs depends to a large degree on the conditions of manufacture and the conditions of warehousing. Deterioration begins initially in the thin film of molasses which envelops every sugar crystal, hence it is this film which must be safeguarded.

Effects of Conditions of Manufacture.

One of the commonest causes of deterioration is the mixing of low grade sugars with high grade sugars. During the process of crystallization-in-motion which the former sugars undergo, ample opportunity is afforded for the massecuite to become heavily infected with micro-organisms. When the sugar is cured in the usual way and then re-cured after mixing with "A" or "B" molasses to obtain a higher polarization, it still contains an extensive micro-organism population. By mixing the re-cured low grade sugars with high grade sugars, the mixture may be of the desired analysis and appearance, but the high grade fraction has been innoculated with micro-organisms by the low grade fraction. Such an undesirable state is eliminated if the low grade sugar is used as a footing (See Chapter VII) for the high grade, because the temperature developed in the vacuum pan produces sterilization. Another important factor is the avoidance of excessive moisture in the molasses film due to incomplete curing of the sugar in the centrifugal. Washing should be carried out using only condensate or other sterilized water. A forecast as to whether a sugar is prone to deterioration or not is afforded by the "Factor of Safety," which is calculated by the following formula :—

$$\text{Factor of Safety} = \frac{\%\ \text{Moisture content of sugar}}{100 - \text{Polarization of sugar}}$$

A sugar is said to be within the zone of safety when the factor so calculated is less than 0·25. The use of processes known to produce hygroscopic substances should be avoided, because of the possibility of the molasses film absorbing water and becoming diluted.

While in transit from factory to refinery, a raw sugar may increase or decrease in either weight or polarization. Some factories attempt to decrease their shipping losses by following the refiners' practice of using a waterproof liner to the bags so that the sugar does not come in direct contact with air. This is unavoidable with the ordinary type of sugar bag if a liner is not used. It also adds to the mechanical strength of the package and the cost is not excessive compared to the possible losses. Nevertheless if the process of manufacture and the conditions of warehousing are correct, very little loss should be incurred.

Sugar Warehousing.

The foremost requisite of a good sugar warehouse is that it should be damp-proof. With this in view, the proposed site must be well drained. The floor is built with a damp-proof layer of asphalt or some similar substance before its final surfacing is completed, so as to prevent moisture absorption through the floor. A similar treatment is used in the walls at ground level. Both the walls and the roof must be completely water tight without windows of any kind. Artificial illumination is used. Similarly, doors should be as few as convenient.

The sugar bags are piled as closely as possible, leaving a narrow lane between them and the walls, together with feeder lanes between the piles. The bags are laid on a false floor of wood, scantling or bamboo mats.

In countries where the relative humidity is consistently high, the warehouse may be air-conditioned, since little deterioration is likely to occur below a relative humidity of 75. When air conditioning is not installed, every precaution must be taken to ensure that moisture-laden air from outside is not admitted and that ventilation is at a minimum. The maintenance of humidity records both inside and outside the warehouse is beneficial, especially if arrangements are made for the rapid exchange of air when conditions warrant this procedure.

The reason for these precautions is that sugar is a hygroscopic substance which rapidly absorbs air moisture. Inversion then sets in, due to the dilution of the molasses film, and the molasses "sweats." The cost of a well designed warehouse is small in comparison to the preventable losses, but an essential adjunct is its intelligent use.

CHAPTER IX.

Processes for the Manufacture of Direct Consumption Sugars.

The description which follows points out the differences which exist in the manufacture of Direct Consumption sugars as compared with the manufacture of Raw 96° Test sugar. The main variations lie in an elaboration of the juice clarification process with a possible further treatment of the syrup. Also, the crystallization and separation processes may be performed differently because of the difference in market requirements of the crystal size of the finished sugar and other features. It is of interest to note at this point that whereas the value of raw sugar is almost exclusively decided by the result of the polarization or other laboratory test, the value of a direct consumption sugar is based on appearance and other arbitrary factors. The latter types of sugar are sold and enter the retail market in the same form as they are made by the factory in the country of origin. Raw sugar does not. It first undergoes a refining process, finally appearing in the market as granulated, castor, cubes or one of the other many forms of refiners' sugar. It follows, therefore, that the direct consumption sugar factory must produce its sugar in such a form that the colour, brilliance, crystal size, etc., will appeal to the ultimate consumer. Certain difficulties may arise in this connection because of the changes which may take place between the time of manufacture and the time of retailing. This statement refers especially to changes in colour and brilliance, which depend to a large extent on the method of manufacture and the conditions and length of time of warehousing.

The more elaborate process of manufacture required is more costly and it is therefore axiomatic that the price obtained must be higher than for raw sugar. Also, the accepted losses occurring in manufacture due to inversion, etc., must be covered.

The different types of direct consumption sugar made from cane juice have been set out as follows :—

I. West Indian Crystallized, Demerara Crystals or Yellow Crystals.

II. Plantation White Sugars.

A. Sulphitation Sugars.

B. Carbonatation Sugars.

Innumerable variations occur, each peculiar to a specific locality. These are not described. The main features of the three above processes are :—

West Indian Crystallized, Demerara Crystals or Yellow Crystals.

The process for making Demerara sugar differs from the raw sugar process in two main features : (*i*) Clarification, and (*ii*) Crystallization. The rest of the procedure is the same.

Clarification.

The clarification process used depends on the requirements of the factory. In some factories, both raw sugar and Demerara sugar are made at the same time. In others Demerara sugar only is made. In the first case there are two alternate methods; either the juice is separated at the mills into Primary and Secondary juice and each is dealt with separately the whole way through the factory, or the whole of the mill juice is treated as for the production of raw sugar and special treatment is applied to the syrup required for the Demerara sugar only. When the juice is separated into Primary and Secondary, the Primary or Crusher and 1st Mill juice is used for the Demerara sugar and is treated the same way as if only Demerara sugar is made, as in the second case. The Secondary or 2nd Mill juice is used for raw sugar and clarified as previously described. The process used when only Demerara sugar is made or when the Primary juice is used for Demerara sugar is as follows : Sulphur dioxide gas (SO_2) is absorbed by the raw juice until a concentration of about 0·05 grms. SO_2 per 100 ml. juice is obtained. Milk-of-lime is then added in such quantities that after heating to 212°F. and settling (See Chapters III and IV), the clarified juice has a reaction of *pH* 6·3 to 6·7. No more exact description can be given because the reactions of the sulphured juice and of the sulphured and limed juice vary in individual instances. Phosphoric acid, if not added before, may be added to the clarified juice which is then heated in eliminators and brushed.

This imparts brilliance to the product. Alternatively, the syrup may be brushed or screened and settled prior to use in the vacuum pan. It is general practice to concentrate the syrup to a density of about 49° Brix (Sp. gr. 1·225 or 27°Bé.) only, as opposed to 58° Brix (Sp. gr. 1·275 or 32° Bé.) for raw sugar manufacture (See Chapter VI). The use of sulphur dioxide in such small amounts and under these conditions does not produce any appreciable precipitate of calcium sulphite, but the value of the application lies chiefly in the bleaching qualities of this chemical.

The alternative process of specially treating part of the syrup only for the production of Demerara sugar is carried out as follows: Syrup from the evaporators produced from clarified juice of *pH* 7·0 to 7·2 has a reaction of *pH* 6·8 to 7·0. It is therefore first sulphured in a tower or sulphitor to produce the required acid reaction of *pH* 6·1 to 6·3. Settling for 6-8 hours then follows before it is used in the pan. Thus the final syrup is of the same reaction as that derived from the sulphured juice process. The difference lies in the added flexibility and in the use of the sulphur dioxide gas after instead of before evaporation.

Sulphur dioxide gas is produced by burning stick sulphur in a specially constructed stove, which may be of more or less elaborate design. Usually, the stove is closed to the atmosphere to prevent the leakage of gas. The air required for combustion is admitted from an air compressor, furnishing air dried by passing it over fresh slaked lime. The gas passes through a cooler and a sublimator before admission to the pipe line and apparatus. The precautions of supplying dry air and of passing the gas through a cooler and sublimator are essential, otherwise the pipe line, usually made of cast iron, and the sulphuring apparatus may be corroded.

The absorption of sulphur dioxide gas is carried out either in a sulphur tower or in a sulphitor. *A sulphur tower* consists of a rectangular wooden tower with a series of horizontal trays set at intervals up its height. The juice is pumped in at the top and cascades down over the trays. The gas is admitted at the bottom and rises through the shower of juice. The surplus gas is vented off through a vent pipe, which also serves to create the necessary gas current. A *sulphitor* is a closed cylindrical

tank usually equipped with mechanical stirring gear. The required amount of juice is admitted and then the gas is bubbled through it from a gas distributor at the bottom. The sulphur tower is continuous in operation, whereas the sulphitor treats the juice in batches. The lime is added to the juice either in the tank at the bottom of the sulphur tower or in the sulphitor.

An *Eliminator* is a rectangular or circular tank fitted with a steam coil in the bottom and a gutter round the upper edge. When filled with subsided juice or syrup, steam is turned on in the coil so that boiling takes place. The liquor, in boiling, forms a froth in which small suspended particles become entrained. The head of the froth is swept off or brushed with a wooden paddle into the gutter.

Crystallization.

The syrup used in the vacuum pans for the production of Demerara sugar is therefore about 27° Bé. density and acid in reaction, *pH* 6·1 to *pH* 6·3. The object is to produce a coarse grained sugar, hence fewer crystals are used in the footing to boil a strike than for raw sugar. The grain size may be further increased by "cutting" the pan, in which part of the contents of one pan are taken into another, then both pans again filled in the normal way. The number of cuts required to produce a product of desirable crystal size varies a great deal and depends primarily on the facilities in the particular factory. The actual boiling procedure is the same as for raw sugar except for differences of a technical nature. The best types of this sugar are made by "topping off" the pan with a charge of "A" molasses. Prior to striking, a relatively small quantity of "Bloomer" is added to the massecuite. This is a chemical which produces the characteristic yellow colour. The sugars are cured in the normal way and are of a brilliant sparkling yellow nature which later turns to brown.

Since Demerara sugar may be classed as a fancy sugar, the actual process of manufacture varies from factory to factory. Each uses an amount of chemicals, for example, which experience shows to give the best results. The process is not therefore so standardized as that used for the manufacture of raw sugar. The importance of the inherent qualities of the juice must not be

overlooked. This factor plays a major part in the maintenance of the grade set by a factory with a reputation for its Demerara sugar. The manufacture of this sugar is carried out in British Guiana and certain of the West Indian islands.

Plantation White Sugars.

The outstanding feature of the manufacture of Plantation White sugars is the elaborate clarification process which is carried out. In the discussion on raw sugar clarification (Chapter III), it has been stated that the basic idea is to obtain (*a*) Coagulation of the colloids, and (*b*) Formation of an insoluble precipitate. The chief object of the elaborate clarification process is to form within the juice a precipitate of much greater proportions than that obtained in raw sugar manufacture, so that the cleaning action is very much more thorough. Such a precipitate is obtained either by the formation of insoluble calcium sulphite (Sulphitation) or by the formation of insoluble calcium carbonate (Carbonatation). It is arranged that the formation of the precipitate takes place within the juice in both processes. It is subsequently removed by subsidation or by filtration, and the juice is left in a much more limpid condition than raw sugar clarified juice. It is evident that such a drastic treatment is more expensive on chemicals and that more elaborate equipment is required in the factory. Similarly, the treatment must be carried out so that the juice qualities are not impaired in any way. This is of special significance (See Chapter III) in view of the large quantities of milk-of-lime which are used.

Sulphitation Sugars.

In the production of sulphitation white sugars, the precipitate formed within the juice is calcium sulphite. Phosphoric acid may also be added. Processes vary as to whether the juice is first sulphured and then limed, or first limed and then sulphured prior to heating. In the Java process, the raw juice is first heated to about 160°F., then the required amounts of lime and sulphur dioxide are added simultaneously with subsequent boiling. The temperature of 160°F. for the preliminary heating is chosen because calcium sulphite is more thoroughly precipitated at that temperature. It is stated, however, that heating to 190°F. may

yield a lighter coloured juice. The equipment required for the production of sulphur dioxide is similar to that previously described. The addition to the juice of both the chemicals is nearly always carried out in sulphitors. The amount of milk-of-lime of 15° Bé. required is approximately twice that used for raw sugar production, i.e., 1·0 to 1·2 per cent. by volume on juice or 3 to 4 lbs. per ton of cane. The sulphur required is half that quantity, i.e., 1½ to 2 lbs. per ton cane, equivalent to a concentration in the juice of 0·08 to 0·25 grms. SO_2 per 100 ml. juice. The precipitate of calcium sulphite and impurities is removed either by subsidation or by filtration. The subsided or filtered clarified juice has a reaction of *pH* 6·9 to *pH* 7·0 and is later lightly sulphured to a reaction of *pH* 6·6 either before or after evaporation.

Bach's process treats the syrup only. Milk-of-lime of 15° Bé. is added to the syrup from the evaporators to the extent of 2·0 to 2·5 per cent. by volume on syrup. Sulphur dioxide gas is then admitted to reduce the reaction to neutrality. The precipitate so formed is then filtered off.

Carbonatation Sugars.

The calcium carbonate precipitate formed within the juice is even more extensive than the calcium sulphite precipitate used in the sulphitation process. In the carbonatation process 7 to 10 per cent. by volume of milk-of-lime is added to the juice either before or simultaneously with the admission of carbon dioxide gas. With the addition of such a large quantity of lime, there is danger of the formation of undesirable products by the combination of some lime with the reducing sugars in the juice if the temperature is allowed to rise too high. The maximum desirable temperature is 125°F. There are several variations of the process which include :

Single Carbonatation.
Double Carbonatation.
De Haan's Modification.

Others also exist, but they are generally of a more technical nature.

Single Carbonatation is carried out in a carbonating tank. Juice from the mill after heating to 125°F. is admitted until the tank is half full. The whole of the lime requirement is then added

and mixed thoroughly, after which the carbon dioxide gas is turned on. As neutralization of the lime proceeds, a highly viscous complex is formed which creates excessive foaming and may overflow the empty half of the tank. During this period the rate of gas absorption is low. Eventually the complex is broken down and gassing proceeds normally. It is continued until the juice has a slightly alkaline reaction. Before discharging the tank, it is a normal safety measure to leave the juice for a few minutes and to check the reaction. If any change has taken place, a further short gassing is necessary. The juice is then reheated to 125°F. and the whole of it filtered. The filtrate is bright and limpid, and is passed through a continuous sulphiting apparatus to acquire the necessary acid reaction prior to evaporation.

Double Carbonatation is essentially the same as single carbonatation, except that the application of carbon dioxide is carried out in two stages. The first stage is started and proceeds as described up to the point of the breakdown of the highly viscous complex. The gas is then turned off after a sample shows a rapidly subsiding precipitate. The juice at this point contains about 0·4 grms. CaO per litre. It is reheated to 125°F. and filtered. The filtrate is sent to the second carbonatation tanks where it is simultaneously neutralized by a further application of carbon dioxide and heated to 212°F. Since no excessive frothing is to be expected, the second carbonatation tank may be filled nearly full. A second filtration follows with sulphitation of the filtrate. This process therefore requires duplication of some of the equipment used in Single Carbonatation. Its advantages are chiefly of a precautionary nature. In single carbonatation there is a danger towards the end of the gassing of some of the already formed precipitate being dissolved. In double carbonatation this danger is removed because the great bulk of the precipitate is first filtered off while the juice is still strongly alkaline.

The essential feature of *De Haan's Modification* is the simultaneous addition to the juice of the milk-of-lime and the carbon dioxide gas. It therefore avoids the formation of the highly viscous complex because the juice never acquires the necessary high alkalinity. After the application of the required amount of lime and when the juice has attained the correct reaction, filtration and subsequent treatment follow as described.

The *extra equipment* required for the carbonatation process therefore consists of carbonating tanks and filters capable of handling the entire volume of juice. Since a plentiful source of carbon dioxide gas is necessary, it is the normal practice for the factory to instal its own *lime kiln*. Calcium carbonate (chalk or limestone) is burnt therein with the production of calcium oxide and carbon dioxide gas. The calcium oxide is hydrated to form milk-of-lime as described (Chapter III) and the carbon dioxide gas is washed and compressed before use in the carbonating tanks. Another possible supply of carbon dioxide is the waste flue gases from the furnace.

The maintenance and operation of the extra equipment make the process an expensive one to operate, but it undoubtedly yields a most attractive juice for white sugar making.

The production of Plantation White Sugars, by any one of the processes, requires a special study of the market requirements. Possession of the necessary features such as crystal size depends on an intelligent organization of the crystallization process, but the colour and sparkle made possible by the intensive clarification process may not be forthcoming because of the inadequacy or inefficient manipulation of the curing and drying equipment. *Curing*, or the separation of the molasses, is carried out in a more thorough manner than for the production of raw sugar. Generally, the massecuite as struck from the pan is first cured in a self-discharging centrifugal. The sugar therefrom is mixed into a magma with a high purity purging syrup, and re-cured in another set of machines. Double curing such as this effects a thorough separation of the molasses, and washing subsequently takes place using "blue" to give a brilliant white to the sugar. Sparkle is obtained by careful *drying*, in which the last traces of moisture are removed from the sugar crystal. It is carried out either by using a steam nozzle in the centrifugal machine, or by passing the centrifuged sugar through a dryer or granulator. When steam is used, it must be dry steam. A *Granulator* is a long slightly inclined revolving drum. Air is heated over steam coils and drawn through the drum from the lower to the upper ends by a fan. The undried sugar is introduced at the upper end. As the drum revolves the sugar is picked up by scoops and cascaded through the current of hot air. Dry sugar is discharged at the lower end

into a revolving screen. The important features of granulator operation are the temperature of the heated air and the rate of air removal. The granulator type of dryer has lately had to compete with the new *vertical tower type.* This is so constructed that the undried sugar introduced at the top of the tower is brought into intimate contact with an upward current of heated air. Dry sugar is withdrawn at the bottom.

In any equipment which is liable to discharge air laden with fine sugar dust, a separator is essential because of the danger of violent explosion.

Comparative Qualities of Sulphitation and Carbonatation Sugars.

It has been seen that both these processes aim at producing a white sugar direct from cane juice. The difference in the two processes is the difference in clarification treatment, and the comparative qualities of the sugars are therefore directly due to this factor. The carbonatation process is very much more drastic in its action than the sulphitation process. This is evidenced by the relative amounts of lime consumed. It is therefore more expensive to operate, and also to instal because of the larger amount of equipment. The compensating factor, however, is the better appearance and keeping quality of a carbonatation sugar, together with an increased yield of the order of 2 per cent. The nature of the chemicals used in the sulphitation process is such that this type of sugar is liable to go off colour. This factor is of importance if the sugar is to be warehoused for any period because it has already been stated that direct consumption sugars are sold mainly on their arbitrary features such as appearance, brilliance, colour, etc.

As regards the technical skill required for their production, both demand a higher order than that usually obtained in raw sugar manufacture and each has its own idiosyncrasies which only experience of the operators can overcome. The quality of both types has been improved with the application of modern methods of procedure and control in the factory. Neither, however, is consistently as good as a refined white sugar. The reason for this is that direct consumption white sugars are not crystallized from such high purity liquors and even a trace of impurity left

in or on a sugar crystal will impart a tinge of colour or dullness to it. When excessive washing in the centrifugal is resorted to, the crystal edges become rounded and dull. Re-crystallization, as is done in refining, is able to eliminate almost the whole of the trace of impurity. It is the approved method of purifying any chemical substance or food stuff.

Plantation Refined White Sugar.

Refined white sugar is produced from raw 96° Test Sugar by a series of processes. They are :—

(*a*) The removal of the molasses film adhering to the crystals.—Affination.

(*b*) Dissolving the resulting purified sugar in water.—Melting.

(*c*) Removal of certain impurities from the melt by precipitation.—Clarification.

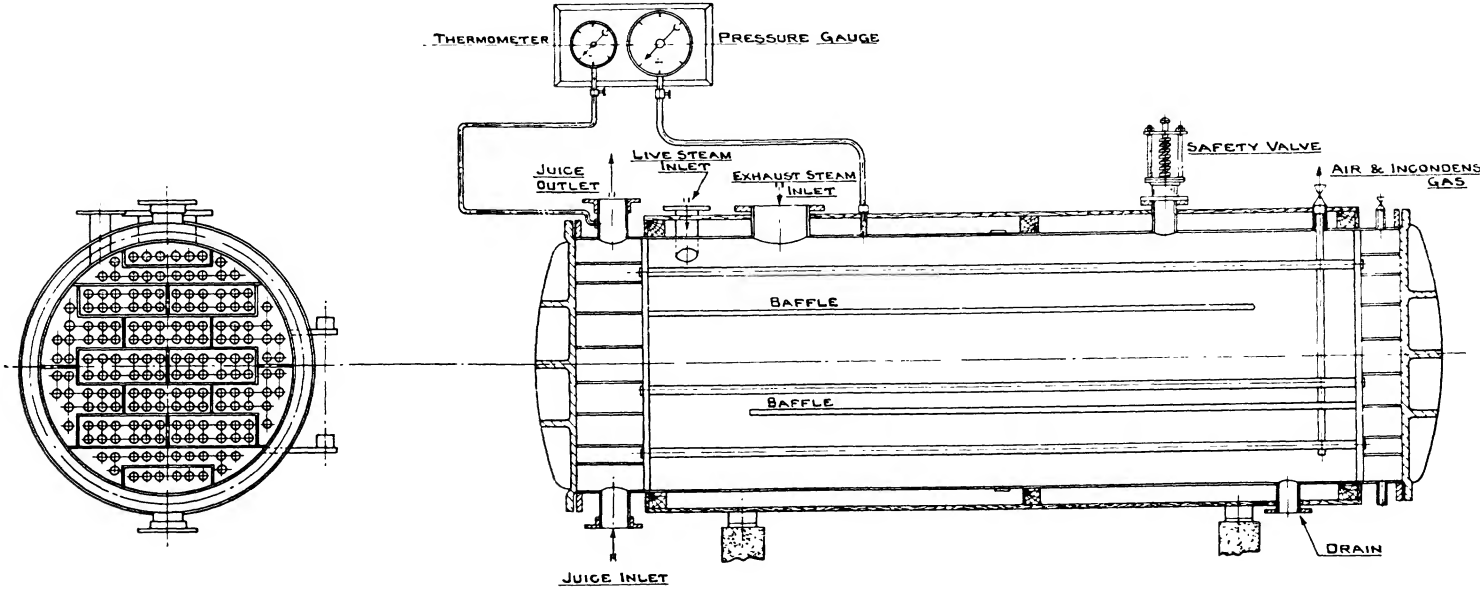
(*d*) Removal of the colour and other impurities by absorption with activated char or carbon.—Char or Carbon Filtration.

(*e*) Crystallization.

(*f*) Separation.

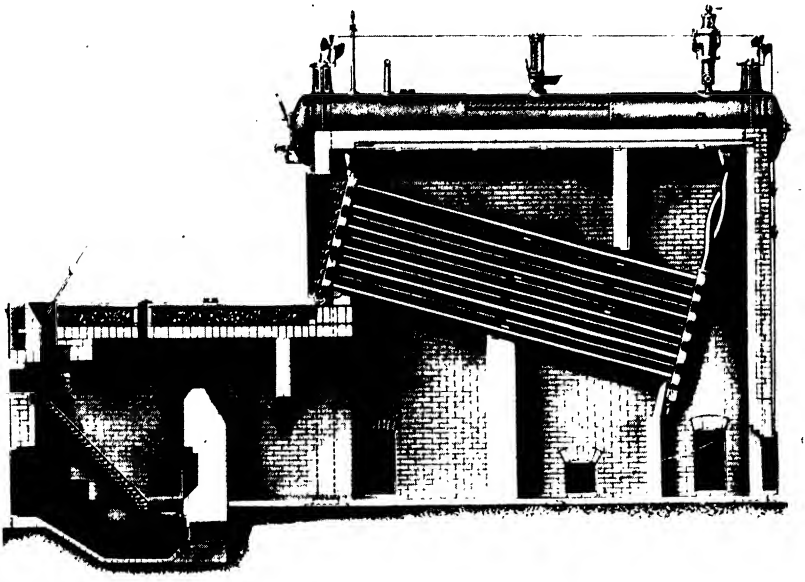
The first point to note as regards white refined sugar manufacture is that the raw material for the process, i.e., raw 96° test sugar, is of very much higher purity than the raw material used to make direct consumption white sugar, i.e., raw cane juice. By far the greater proportion of the impurities in raw 96° test sugar is contained in the film of molasses which envelops each crystal. The first operation which the refiner performs is therefore the removal of this film. The resulting sugar is then dissolved in water to form a turbid melt. The preliminary clarification is carried out with phosphoric acid and lime in much the same manner as in raw sugar clarification and it produces a liquor suitable for activated char or carbon filtration. This results in a brilliant water white liquor, and the processes of crystallization and separation are carried out as already described.

The recent advent of activated vegetable carbons, such as Suchar, Sumacarb, Norit, etc., has been the means of enabling certain plantations in Puerto Rico, Cuba and other countries to refine their own raw sugar. The older established char process is one which demands all-the-year-round operation at compara-

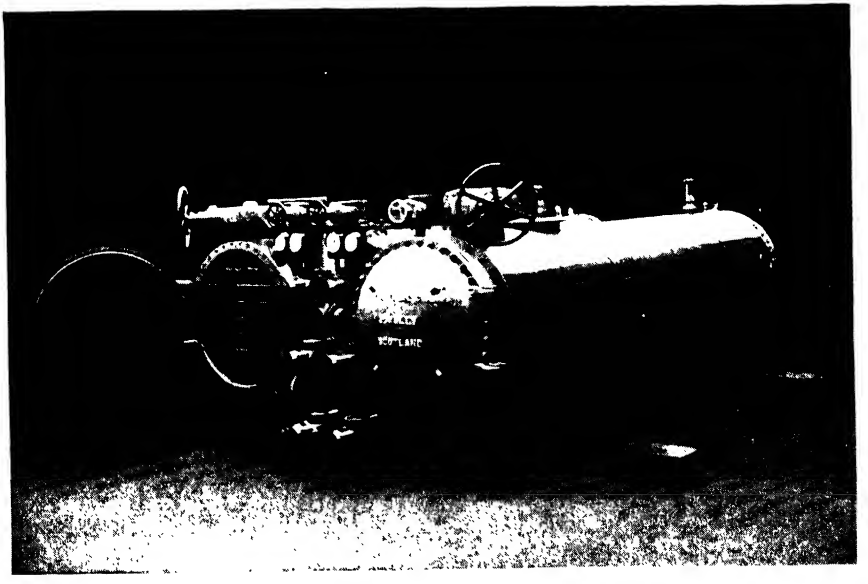


HIGH VELOCITY HORIZONTAL JUICE HEATER.

(H. W. Aitken Co. Ltd.)



Water Tube Boiler and Furnace for burning Bagasse.
(*Babcock & Wilcox, Ltd.*)



Multi-Pass Horizontal Juice Heaters.
(*H. W. Aitken Co., Ltd.*)

tively high capacities. Another disadvantage from the plantation point of view is the heavy water consumption. As opposed to this, the activated carbon process is relatively simple, it is capable of economically handling small outputs, the initial investment is smaller and little wash water is required. One of the main disadvantages is the revivification of the carbon, which in the char process is now highly developed with low char replacements. Some carbon manufacturers have overcome this by developing a revivification technique and equipment of their own such as Suchar and Norit, while others produce a carbon, such as Sumacarb, which is not revivified and the cost is correspondingly cheaper.

Within the last year or so, a chemical refining process known as Sucro-Blanc has been perfected and successfully used in some factories. No activated char or carbon is necessary, since the essential part of the process eliminates these. Like the carbon processes it is designed to deal with raw 96° test sugar and to produce refined white on the plantation.

By refining at the raw sugar factory, charges such as bagging, warehousing, ocean freight and insurance, dock dues, etc., are saved on the raw sugar, refiners profits are eliminated and the cost of transport of the refined sugar is reduced because of the elimination of impurities.

Comparative Qualities of Plantation Refined and Plantation Direct Consumption Sugars.

Modern methods of refining on the plantation produce a sugar which, to all intents and purposes, is equivalent to the char refined product. It is therefore superior to either sulphitation or carbonatation white sugars because of the second process of clarification and recrystallization which has taken place. Following on this, the cost of production is higher for the same reason. When a new white sugar factory is to be laid down, the choice of the sulphitation, carbonatation or refining process is made according to the probable remuneration to be obtained on the available market. If the white sugar is to be exported, the import duty in the consuming country will probably be on a polarization basis. In this respect neither of the three processes will show any advantage, unless different duty scales are made out for refined and unrefined sugars.

CHAPTER X.

Fancy Molasses.

Fancy Molasses, or Cane Syrup, is manufactured direct from cane juice. It is not to be confused with Golden Syrup, which is a refinery product. Generally, the best quality Fancy Molasses is made by small factories equipped with simple mills where only the purest juice in the cane is expressed and treated. As a food it contains all that was in the original juice, except those substances precipitated by the clarification process. Since no crystallization of sucrose is allowed, there are three main objects in the manufacture :—

(*a*) Clarification, so that the juice before further treatment is clear and bright.

(*b*) Concentration, so that the greater part of the water content of the juice is removed, and

(*c*) Inversion, so that a proportion of the sucrose present is changed to non-crystallizable sugar.

Desirable Characteristics of Fancy Molasses.

Fancy molasses is sold on the basis of density, polarization (which controls lack of crystallization or "sugaring"), colour and taste. Buyers demand a density of 41° Baumé, equivalent to approximately 77° Brix. Lack of crystallization is controlled solely by the degree of inversion obtained during manufacture. A product containing sucrose equivalent to a polariscope reading of 32° to 37° should not show signs of sugaring when sold. Uniform colour and taste are of the utmost importance. Since Fancy Molasses for the table is generally made in a number of small factories in any one locality, co-operative blending is the only feasible method of producing uniformity. One consignment can then be blended to the same characteristics as any other, and the buyers attain confidence in the uniformity. The colour desired is a bright reddish-brown, with a full flavour produced by slight fermentation.

Process of Manufacture.

Juice Extraction.

The juice is extracted from the cane by milling units of standard design. In the average molasses factory, the mill unit consists of a three to eight roller tandem driven by animal, water, wind or steam power. The degree of extraction is therefore not comparable to the heavier units in sugar factories. This, in a way, is a safety factor because only the relatively pure pith juice is extracted which yields easily to clarification treatment.

Clarification.

The basis of an attractive looking syrup is adequate clarification. Milk-of-lime is added so that after heating and settling the juice is clear and bright. Standard raw sugar methods are used except that heating is usually carried out in tanks equipped with steam coils or heated direct by flue gases. An important difference from raw sugar practice is the acid reaction of the clarified juice, about *pH* 6·0. The reason for this is that the juice is made more acidic later in the process, hence the less the amount of lime that is used in clarification the less the subsequent amount of acid to be added. It is characteristic of most cane juices that an adequate clarification is obtainable both on the acid and on the alkaline side of neutrality. In fancy molasses manufacture, inversion of sucrose by acid and heat is therefore encouraged; while in sugar manufacture the inversion of sucrose is prevented.

It is evident that to obtain an efficient clarification, subsidation must be as complete as possible. There should be no difficulty in clarifiers of the usual type but when the juice is heated by flue gases and settled in the same tank, proper subsidation is difficult unless there is an arrangement of flue dampers.

The clear supernatant juice is decanted, and the settlings may or may not be filtered.

Concentration.

The clear juice from the subsiders is then concentrated. This is carried out either in a multiple effect evaporator of standard design (See Chapter VI) or else in an open pan or *tayche*. Tayches may be used for a preliminary concentration prior to finishing in a steam-heated pan. They are built into a brick flue and come in

direct contact with the flue gases, so that local overheating of the syrup probably takes place, resulting in some caramellization. An open steam-heated pan of the Aspinall type is more desirable, and the rate of evaporation is more easily controlled. In some of the old factories, the tayches were also used for completing clarification. As boiling took place, the scum which rose to the surface was skimmed off with paddles. The liquor was ladled from one tayche to the next. Probably the best arrangement is to carry out a preliminary concentration in a multiple effect evaporator and the final concentration in a steam-heated pan open to the atmosphere.

Inversion.

In order that the final product does not deposit crystals of sucrose, the greater part of the sucrose content is inverted or changed to reducing sugars (See Chapter III). The process of inversion takes place simultaneously with that of concentration. The rate at which inversion proceeds depends on :—

(*a*) Temperature.

(*b*) Hydrogen-ion concentration, *pH* or acidity (See Chapter III).

(*c*) Concentration of sucrose.

The amount of inversion desirable introduces a time factor. Hence, the higher the temperature, hydrogen-ion concentration and concentration of sucrose, and the longer the time of reaction, the greater will be the amount of inversion. In practice, these factors must be considered and the actual procedure regulated to the requirements or limitations of the existing equipment. The temperature attained during inversion depends on whether concentration is carried out in vacuum evaporators of standard design or in open steam-heated Aspinall pans or direct-heated tayches. The hydrogen-ion concentration is adjusted by the addition of (*a*) sour juice, (*b*) an organic acid, or (*c*) a mineral acid. The use of sour juice is not to be encouraged because cultivation, cutting and transport charges have been paid on the cane, and the inverting strength of sour juice is relatively very weak. The method is therefore expensive and inefficient. An organic acid such as crude vinegar or concentrated lime juice has the same disadvantage of being a weak inverting agent. Also, the latter is difficult to obtain

in standard strength. By far the most successful is a mineral acid. The one to be used should be chosen so that the Pure Food Laws are not violated. Some acids are precipitated and removed after concentration is completed. The method is cheap and the results are positive. The amount to be added to the liquor is about 1 in 6000 but varies within limits with the conditions.

After-treatment.

When concentration and inversion are completed, the product is run down into coolers before being stored in cisterns for subsequent barrelling. Hot syrup in the cisterns will lead to charring and a darkening of the colour. Cooling is therefore an essential but simple step before storing. Also the coolers allow any further precipitate to settle out. The syrup is shipped in casks of 55 wine gallons or in puncheons of 110 wine gallons.[1]

Control of the Process.

Once the buyers' requirements have been established, the process of manufacture must be controlled accordingly. A density of 41° Baumé necessitates concentration to a density of 36° Baumé when measured on the hot liquor. This is more easily controlled by boiling to a certain temperature. It has already been pointed out that the boiling point elevation varies with the concentration (See Chapter VI). The boiling temperature in open pans equivalent to 36° Baumé is 224°F. It can be easily measured by immersion of a suitable thermometer in the boiling liquor. Lack of crystallization is controlled, as stated, by the degree of inversion. The best method of control is by means of a series of polariscope readings in conjunction with Hydrogen-ion concentration measurements in a *pH* colorimeter of suitable type. These determinations are carried out at various stages during the manufacturing process. Once the required conditions are established, the procedure can be standardized and then checked periodically.

[1] Equivalent to 45 and 90 Imperial gallons respectively.

CHAPTER XI.

Transport.

For every ton of sugar manufactured by the factory, ten to twelve tons of material must be transported. In order that the rate of grinding may proceed at the desired rate, transportation must be carried out on a predetermined schedule. With material liable to rapid deterioration such as sugar cane, harvesting and manufacture must therefore be synchronized. Transport is the important connecting link. It also has the additional task of having to remove the factory products. It is to be further remembered that harvesting is only possible during a certain period of the year. A delay due to faulty transport or a factory breakdown is time and money lost. With certain other industries, the raw material can be stored and accumulated and then used as required. The cane sugar industry is not in such a happy position. Sugar cane loses in weight and in sugar content from the time it is cut until it is milled, hence a definite time factor enters into the transport organization.

Almost every known method of transport, except perhaps air, is employed in the industry. The actual type used depends primarily on local conditions.

Water Transport.

Certain countries, notably British Guiana, grow cane on land below high tide level. Each field is bounded on all four sides by canals, some of which are drainage canals and others transport. The system of transporting cane from the field to the factory is to load the cane after cutting into steel or wooden punts which are towed in batches of three by a mule into the factory dock. The punts are then unloaded and returned to the field. Each punt load is of about 3 to 5 tons of cane. In order to expedite unloading, three or more sling chains are laid from one side of the punt to the other, so that the cane forms a bundle which can then be lifted out by means of a derrick or similar device. The digging of the canals could only have been carried out by virtue

of the old slave labour, and few extensive additions are now made. The water level in the canal is maintained by pumping from a creek or river, and this is one of the most expensive operating costs. The main disadvantage against this type of transport is the slow speed of delivery. Animal towing is the only feasible method of locomotion because the structure of the canal is usually such that a power-driven towing unit on the bank or afloat cannot be used.

Apart from British Guiana, water transport is used for delivering canes grown in one island to a factory situated in another in at least two instances in the West Indies. Sloop or steamer is used. Fundamentally, this constitutes the export of sugar cane as a raw material and is only justified when distances are short.

Nearly all the world's cane sugar is sea-borne at one time or another prior to consumption. This refers particularly to raw 96° test sugar. Before loading on to the ocean-going steamer, many coastal factories ship their sugar to the nearest port in lighters or barges.

The importance of final molasses as a raw material for the production of industrial alcohol and other substances has resulted in special tankers being built and designed solely for this purpose. The use of an oil tanker results in possible tainting, and has a further disadvantage in that the steamer obtains a full cargo in weight without all the tanks being used because of the difference in weight per gallon between oil and molasses. This results in cargo surging and difficult navigation.

Road Transport.

For short distances, animal-drawn carts are in extensive use especially among small farmers. The carts are either two or four wheeled and carry from ½ to 4 tons of cane. When the wheels are steel tyred or of steel construction, they are five to eight feet in diameter and correspondingly wide. Recently pneumatic tyres have come into prominence for use with animal-drawn vehicles. While the cost of the tyres, wheels and axle is in excess of the ordinary wooden steel-shod wheels, the benefits amply repay the extra outlay. Less tractive effort is required and the

animals keep in better condition, the roads and traces are not cut up, and no damage is done to the cane stools in the field when hauling out. The last two features are also to be found in the caterpillar-equipped carts.

Mechanical traction by lorry with or without trailer or by a tractor hauling a train of trailers requires roads surfaced to withstand the heavy loads. Diesel-engined units are proving themselves economical. A new development is the use of a single short wheelbase motor truck chassis working in combination with a set of two or three two-wheeled trailers. The trailers are loaded, transported and unloaded alternately. The effective working time of the truck unit and its crew is materially increased over that of the ordinary motor lorry, which has to wait while loading and unloading are being carried out.

Rail Transport.

This is the commonest system used in the industry, the gauge varying from light tramway to full sized railway. Loading points are established in the fields to which the cane is brought in animal or power drawn carts. An alternative method is to use portable track which can be laid in the field being harvested. The trucks after loading are then taken to the railhead or factory yard. The type, size and construction of the trucks vary over wide limits and steel is finding favour as the material in place of wood. They may have one, two, three or four compartments. Truck capacities range from ¾ ton to 35 tons of cane. Those used for the transport of sugar are either covered trucks or equipped with a tarpaulin of suitable size.

Locomotives similarly vary over wide limits. They may be classified as :—

(*i*) Steam-driven ; oil, coal, wood or bagasse fired.
(*ii*) Diesel engined.
(*iii*) Electric.
(*iv*) Diesel-electric.
(*v*) Petrol engined.

The *steam-driven locomotive* is the commonest, the type of fuel to be used depending on local conditions. The use of surplus bagasse requires that this fuel should be briquetted, and certain

alterations have to be made to the locomotive. So far it would appear that a bagasse-fired locomotive is only suitable for shunting in the yard or on lines which have no appreciable gradients. With any fired locomotive, special precautions must be taken to eliminate the emission of sparks because of the danger of cane fires in the fields. Spark arresters are installed on the smoke stacks. For short distances, the fireless steam locomotive has proved its utility. This engine has no grate, the "boiler" being charged with steam from an outside source, such as the factory boilers.

The *geared Diesel engine* is used on comparatively heavy locomotives for general plantation work. Varying forward and reverse speeds are obtained by the use of a gear box of similar principle but different in design to that on the ordinary automobile. The use of *electric locomotives* is not very extensive but a point in their favour is the possible use of surplus factory power generated by burning bagasse and distributed by overhead wires. A *Diesel-electric locomotive* is a self-contained electric generating unit. It has most of the advantages of the electric locomotive and no overhead power distributing wire is required, thus eliminating possible danger to labourers. In Hawaii it has been found that the operating costs are lower than the corresponding steam unit. The *petrol-engined locomotive* is only found in small sizes because the fuel consumption is higher and the cost of the fuel greater than in the Diesel engine. It is used for such duties as shunting round the factory yard. The fuel cost is materially reduced if the factory is equipped to make its own alcohol from the final molasses.

As regards the permanent way, the first point to be settled is the gauge to be used. For short distances, with the major part of the cane near to the factory a narrow gauge is suitable, although other considerations may influence this choice, such as the possible use of rolling stock over the public railway, gradients, etc. The weight of rail is similarly influenced largely by the gauge, and wear and tear and maintenance charges are reduced if a heavy rail is used. Generally, the permanent way is laid on wooden or steel sleepers, but there is a recent suggestion to substitute concrete on the grounds of an expected longer life. Before the railway is laid out, the land to be serviced must be carefully surveyed, not

only to obtain the optimum distribution but also to decide the probable comparative costs of gradients, embankments, bridges, curves, tunnels and so on. A railway represents a considerable investment and it is obvious that it should be laid down to the best advantage.

Overhead Ropeways.

This type of transport is used for one of two purposes, either to traverse mountainous country, rivers or valleys, or else on flat or broken land. The former may require spans up to 2000 feet, but in the latter they are very much less because of the series of supporting poles. There may be either a single rope or cable for both supporting and moving the bundles of cane or a separate cable may be used for each purpose. The power is derived from a winch. Under hilly or mountainous conditions gravity may be used. The method is limited in its carrying capacity.

Flumes.

A flume is a continuous metal or wooden gutter of adequate cross section, down which the cane is floated by a stream of water. While being simple in operation, the main drawback is the relatively immense quantities of water required, something of the order of a million gallons per 240 tons of cane transported. In Hawaii, where this system finds its most extensive use, ample water is available in the mountains on the sides of which the cane is grown. An obvious disadvantage is that it provides one way transport only, and substances soluble in water such as fertilizer cannot be moved by it.

CHAPTER XII.

The Utilization of Factory By-Products.

Certain by-products are formed during the recovery of sugar from sugar cane. They are bagasse, filter cake and final molasses. The utilization of each of these is discussed herewith :—

Bagasse.

A factory produces from 22 to 30 per cent. of the weight of cane as bagasse, and the main outlet is its use as a fuel for raising steam to run the factory. This has been discussed in Chapter II. In certain factories, there is excess bagasse over and above the fuel requirements. Bagasse is a bulky material, difficult to transport and to store. The surplus is therefore compressed into bales or briquettes. It is used, or has been tried, for the following purposes :—

(*a*) Disposal to other factories with a bagasse deficit.

(*b*) Used as fuel for the plantation locomotives.

(*c*) Used as bedding for stock.

(*d*) Used as a mulch in the fields.

(*e*) Incorporated with final molasses to form a dry stock feed, such as "molascuit."

(*f*) Used as a raw material for paper making, artificial silk, etc.

(*g*) Treated with chemicals such as caustic soda, sulphuric acid and lime to make a plastic.

(*h*) Turned into synthetic lumber such as "Celotex," "Vazcane," etc.

Certain of these require no further explanation, others are too complex for use on the plantation without special technical advice and extensive machinery. Bagasse as a fuel for plantation locomotives has been discussed in Chapter XI. When it is mixed with final molasses to form a stock feed, it is important that thorough impregnation should be accomplished. Since bagasse contains 45 to 50 per cent. moisture, a preliminary drying is first

carried out, so that its full value as an absorbent is utilized. The result should be a dry meal which can be bagged and transported without expelling molasses.

Filter Cake.

Filter cake is produced to the extent of one to four per cent. of the weight of cane. It is used as a manure for the fields because of its nitrogen and phosphate contents. The analysis varies according to the clarification process adopted in the factory. Its utility as a manure has been placed as equal to that of farmyard manure. The value is however offset to some extent by the difficulty experienced in spreading it evenly over the fields. A method has been tried in which the cake is made into a free flowing paste or slurry, transported to the fields in tank cars and distributed in the ditches.

In some countries, the wax content of the filter cake is high enough to warrant the establishment of a central wax extracting plant.

Final Molasses.

The production of final molasses varies from 3 to 6 gallons per ton of cane ground. Such a quantity may, under certain conditions, be a definite embarrassment, and disposal then takes the form of running to waste. This operation in itself is not easy because of the inherent qualities of the material, unless the factory is situated on the coast. Molasses may however be used for other and more profitable purposes.

Fertilizer.

Molasses contains potash, nitrogen and phosphate. It is therefore a cheap source of supply of these nutrients, although they do not represent the major constituents. The chief difficulty in its use for this purpose is one of distribution, but when this is overcome, significantly increased growth yields are obtained. Attempts have been made to mix molasses with furnace ashes, filter cake and bagasse, so that a more convenient product is formed. In certain areas, the benefit derived from an application of molasses as fertilizer shows a delayed action. There is however a sustained residual effect. Light applications are reported to show an immediate response under most conditions.

Rum.

The fermentation of molasses with subsequent distillation and the production of a potable spirit was the first attempt by the cane sugar industry to make a by-product. The *rum* which is so produced varies widely in flavour and alcohol content. The reason for this lies in the differences in analyses of the original molasses and the differences in variety of the characteristic organisms bringing about the fermentation. Other factors, such as type of still and temperature of distillation, also play their part. Rum is defined in Great Britain as a spirit distilled from fermented products of the sugar cane in a country where the sugar cane is grown. Its characteristic flavour is said to be due to the presence of ethyl esters.

Fermentation is carried out by diluting the thick molasses with five to six times its volume of water. This reduces the specific gravity to 1·060—1·063. Sulphuric acid is then added to suppress the growth of undesirable yeasts and bacteria, and sulphate of ammonia to supply the desirable yeasts with nitrogen. Fermentation sets in spontaneously. There are two types : (*i*) When the maximum amount of light and air is admitted to the vats the alcohol yield is high and the process is completed in 48 to 72 hours ; (*ii*) when the process is carried out under closed and dark conditions, some of the alcohol yield is sacrificed and complete fermentation takes 8 to 14 days. The completion of fermentation is signified by the cessation of foaming and the dead yeast cells fall to the bottom. The specific gravity of the fermented wash is then measured. The difference in the readings before and after fermentation is called the *attenuation*. A theoretical yield of alcohol can be calculated by assuming that for each 5° attenuation 1 per cent. of alcohol is produced. The fermented wash is transferred from the vats to the still, of which there are several types. A general classification of *stills* is as follows :—

1. Direct fired or steam heated.
2. Intermittent or Continuous.

Direct-fired stills are now seldom used except for small outputs. They take the form of a copper vessel set in a brickwork flue. Steam heated types, on the other hand, are almost

universal. The designs allow fractional distillation to take place either intermittently or continuously. The latter are the more economical and produce a more uniform spirit. They consist generally of two main vessels, the analyser or retort, and the rectifier. The vapours issuing from the rectifier are cooled in a condenser and run through Excise-sealed pipes to the similarly sealed storage vats. The rum so obtained is water white. The alcoholic strength depends on the conditions of distillation. Prior to bottling-off, the spirit is coloured by the addition of caramel and matured for varying lengths of time under varying conditions. The *obscuration* of rum is the difference between the actual proof spirit and the apparent proof spirit as determined by an immersion alcoholometer. It is legally set at a certain definite figure. *Faulty rum* is rum which, on dilution with water, becomes cloudy and throws down a precipitate. It may be due to one of several causes.

Industrial Alcohol.

Molasses is also one of the main sources of industrial alcohol. It is produced by the same series of processes as rum. The dilution of the molasses and the fermentation of the wash are carried out and controlled in such a way that the yield of alcohol is at its maximum. A pure culture yeast is used and the wash is aerated. When fermentation is completed, distillation follows, using the same type of still as described. Prior to use of the azeotropic principle in certain modern processes, the distillate contained about 96 per cent. alcohol. Absolute alcohol was then obtained by an irksome process of dehydration. The modern processes produce absolute alcohol direct from the fermented wash and at lower cost than before. The product can be used as a motor fuel for plantation locomotives, automobiles, etc., or for any of the other industrial uses.

Use of Distillery Lees.

The lees or dunder contain all the original constituents of the molasses except that part of the carbohydrates which has been fermented and distilled. Molasses lees is unsuitable for a cattle food. It contains, however, a high proportion of potash which can be recovered and used for fertilizer purposes. The recovery is carried out in a special type of Open Flame Oven.

Compressed Yeast.

Compressed Yeast is another product which can be obtained from molasses. The molasses must, however, be specially treated before being pitched with the desirable yeast, which is afterwards recovered and packaged.

Recovery of Carbon Dioxide.

During fermentation, 96 parts of carbon dioxide are produced for every 100 parts of alcohol. The gas can be recovered by placing a hood over the vats and installing suitable scrubbers, etc. It is then compressed and charged into cylinders or solidified. It is used commercially for the manufacture of carbonates and of aerated drinks, in fire extinguishers and as a refrigerant.

Special Products and Other Uses.

Processes have been worked out whereby such products as butanol, acetone, glycerine, citric acid, butyric acid, etc., are manufactured from final molasses. Its other uses include stock feed, after dilution; mixing with mortar for brickwork; as a cereal substitute, etc.

CHAPTER XIII.

Chemical Control.

The chemical control of a sugar factory may be sub-divided as follows :—

Weights and Measurements
Sampling Factory Products
Laboratory Analyses
Stock-taking
and Control Reports

Since the essential purpose is to estimate yields and losses, it may be compared to the accounting and auditing of the business department. The whole value of chemical control is however completely nullified if the accuracy of the basic data is not of the highest order. Losses may then be taking place which continue undetected. No reasonable expense should therefore be spared in supplying accurate equipment for weighing, sampling, analysing, etc.

Weights and Measurements.

At the outset it should be stated that in all cases weights are to be preferred to measurements. Weighing machines are however expensive and are seldom available at all required points. For comprehensive chemical control, the weights of the following are required :

Cane.

It is desirable that the cane should be weighed immediately before being unloaded from the truck on to the cane carrier. The reason for this is that from the time of harvesting until the cane is milled, there is a continuous loss of weight. Hence, when there is a time lag between weighing and milling, less weight of cane is actually milled than that shown by the scale house returns.

Maceration Water.

The weight of maceration water is obtained by one of three methods : (*a*) by weighing ; (*b*) by measurements, and calculation

of the weight from the volume ; and (*c*) by calculation from the calculated dilution water (see Control Reports). The only strictly accurate method is when cold water is weighed and used.

Mixed Juice.

The mixed juice weight is obtained either by weighing or by measurements and calculation therefrom. In certain factories it is obtained by measurements of the hot treated juice in the clarifiers, in which case temperature and other corrections have to be applied. The most desirable place for the mixed juice weighing machine or measuring tanks is between the mills and the liming tanks, so that no correction has to be applied for added milk-of-lime or returned juice. There are several suitable types of weighing machines, ranging from fully automatic to manual operated. One of the former type which is foolproof and accurate saves labour and possible error therefrom, and only periodic checking is necessary. Calculation of the weight from measurements is liable to involve a series of errors, which in turn result in an inaccurate control report. Elimination of such errors is difficult under the ordinary operating conditions of the factory, even with special supervision, and the weight of mixed juice is of extreme importance.

Bagasse or Megass.

Most Technologists Associations accept the weight of bagasse as that obtained by difference (see Control Reports). Equipment is available, however, with which an actual weight can be recorded. It is evident that when obtained by difference, any errors in the weights of the other items in the equation will correspondingly affect the weight of the bagasse.

Filter Cake.

The ability or otherwise to obtain an accurate weight of filter cake depends to a large extent on the particular layout of the factory. Ideally, the cake immediately after discharge from the filter is weighed on a suitable scale. A method commonly used when filter-presses are installed is to weigh the cake from one or more frames and to multiply the average weight so obtained by the number of frames in the filter.

Final Molasses.

The nature of this material makes it difficult to measure, unless special arrangements are installed. Weighing is therefore considered essential, especially in view of the significance of the figure. The chief error in measuring a tank is that brought about by occluded air in the molasses. This not only artificially increases the volume, but also forms a foam on the surface which cannot be clearly differentiated from the molasses.

Sugar.

The weight of sugar is of obvious importance. It may be obtained by an automatic scale placed on the mouth of the hopper, or by a reliable type of manual operated machine. In either case, every fifth, tenth or twentieth bag should be checked.

Sampling Factory Products.

Factory products are sampled throughout the various stages of manufacture so that by analysis and calculation recoveries, losses and inefficiencies of operation can be detected. The sampling procedure is therefore of importance because it is the first step in this process. Sampling, whether carried out mechanically or manually, must be honest and accurate. The sample must represent, in all its relevant characteristics and in as small a bulk as desirable, the large volume of material from which it was derived. Changes in composition, due to evaporation, deterioration, etc., are not to be tolerated. Sampling methods vary according to the characteristics of the product to be sampled. Some products allow of the use of wholly automatic devices, others require manual sampling. An automatic device should be such that automatic regulation comes into effect so that the rate of flow of the sample into the container varies in direct ratio to the rate of flow of the material in the pipe line, gutter, etc. Manual sampling depends for its success on the operator. Certain fundamental rules should be laid down as a guide to the frequency and quantity of collection.

The following products are sampled for analysis : Crusher juice, Mixed juice, Last Roll juice, Bagasse, Clarified juice, Filter cake, Evaporator supply juice, Syrup, Massecuites, Molasses and Sugar. Most of the juices, with the exception of Last Roll

juice, can be sampled automatically by suitable devices. Manual methods take the form of collecting a definite volume in a specified manner at certain time intervals. Last Roll juice is sampled manually across the full width of the roller simultaneously with the taking of the bagasse sample across the full width and depth of the chute. Syrup and molasses are sampled automatically or by the tank-full. Massecuite samples are collected at the discharge valve of the pan after one-third of the strike has been emptied out. Filter cake is sampled according to the type of filter in use. It must be remembered that the composition varies with the position of the cake in or on the filter. Sugar is sampled from every bag or every tenth or twentieth bag, a convenient time being when the bag is weighed or checked. No specific instructions are put forward here because the method and frequency of sampling the different products varies with the laboratory requirements and the factory equipment.

Sample Containers.—A sample container should have a hard smooth surface, free of cracks and crevices, so that washing and drying after use each time is easily carried out. It should be provided with an airtight cover. Two complete sets are required, one in the factory and one in the laboratory. The name of the product to go in each container should be marked plainly thereon so as to eliminate confusion.

Sample Preservatives.—A preservative is generally added so that no deterioration takes place while the sample is being completed. It should be such that there is no interference with the analysis. Alcoholic mercuric chloride, formaldehyde and lead sub-acetate each have their specific uses.

Laboratory Analysis.

It is not proposed to describe here the actual methods of analysis because they can be obtained from any of the standard textbooks on the subject. An attempt is made, however, to discuss the fundamental principles involved and the basic ideas underlying the various groups.

The laboratory analyses may be divided into the estimation of the following: (1) Density; (2) Sucrose; (3) Reducing Sugars; (4) Moisture; and (5) Other Determinations.

Density.

The significance of the density determination lies in the necessity for knowing the amount of solids in solution in the various factory products. It is determined by one of four methods : (*a*) Hydrometer ; (*b*) Refractometer ; (*c*) Specific Gravity Bottle or Picnometer ; and (*d*) Drying.

The *hydrometer* used in the sugar industry is that due to Balling which was afterwards corrected by Brix. It is known as the *Brix* or *Brix-Balling* hydrometer. The scale is so graduated that in a pure sucrose solution the reading gives the grams of sucrose present per 100 grams of solution. The result therefore indicates the percentage by weight of sucrose present. It is only correct when the solution is at the temperature at which the hydrometer was graduated. For temperatures other than this, a correction has to be applied. Most hydrometers used in tropical factories are graduated at 27½°C. and may include in the bulb both a thermometer and a correction scale. When the density of an impure sucrose solution, such as juice or syrup, is determined by the Brix hydrometer, the result is one in which all soluble constituents are expressed in terms of sucrose. There is therefore an error because the "constituents-not-sucrose" and sucrose do not necessarily have the same effect on the hydrometer. The error varies with the proportion of sucrose to other constituents present and with the concentration. For control purposes, the error is generally neglected.

A *refractometer* is an instrument which measures the degree of refraction. Refraction takes place when a beam of light passes from one medium to another, for example from air to water. It varies with the concentration of substances present in the water. It is therefore possible to correlate the degree of refraction, or refractive index, with the concentration of sucrose present in a sucrose solution. Laboratory refractometers are graduated either in refractive indices or in per cent. sucrose by weight, i.e. degrees Brix. When used on impure sucrose solutions, the same error is present as in the hydrometer method, but the magnitude of the error is not so great.

The estimation of *specific gravity* by means of a picnometer bottle is a standard physical method. For laboratory control

purposes it is tedious and seldom used, and special precautions must be taken to rid the sample of occluded air.

The estimation of density by *drying* is essentially the same as the estimation of moisture. The conditions under which all the water is removed must be such that no decomposition of the constituents takes place. It is for this reason that the drying of cane products is carried out under conditions of reduced pressure and temperature. The method, in contrast to the hydrometer and refractometer, yields an accurate result which is expressed as the *per cent. Total Solids.*

Generally, the Brix hydrometer method is the one used in the laboratory, although the refractometer, because of its accuracy and rapidity, is finding favour for certain purposes.

Sucrose.

The estimation of the sucrose content of a product, known in the case of a sugar as the degree polarization, is carried out with the aid of a *polariscope.* Ordinary light is conceived as a series of transverse vibrations in the ether. By passing ordinary light through crystals of certain substances it becomes plane polarized, that is, the ether vibrations of the emergent ray take place in one plane only. Solutions of sucrose, in common with those of certain other substances, are able to rotate the plane of polarized light. The degree of rotation is proportional to the length of column of the solution through which the ray passes and to the concentration of the solution. Hence, if the length of the column is standardized, the concentration may be estimated by measuring the degree of rotation. The crystal through which the light is passed is a Nicol's prism made from Iceland spar. Two Nicols are used, one at each end of the column. Polariscopes made especially for the estimation of sucrose are known as *saccharimeters.* Modern saccharimeters are equipped with certain refinements in order to increase the accuracy and to facilitate the reading. They further differ from polariscopes in that the scale is divided into one hundred parts instead of into angular degrees. If the solution of sucrose is made up and the saccharimeter reading obtained according to certain specific instructions, the scale will indicate the percentage of sucrose present in the original material. It has been stated that the degree of rotation varies with the length of the column

After determination of sucrose and of density in terms of degree Brix, the former is expressed as a percentage of the latter and called the "purity" of the solution. Depending on the method used, the purity is calculated as follows :—

$$\text{Apparent Purity} = \frac{\text{per cent. Pol.} \times 100}{\text{degree Brix}}$$

$$\text{Gravity Purity} = \frac{\text{per cent. Sucrose} \times 100}{\text{degree Brix}}$$

$$\text{True Purity} = \frac{\text{per cent. Sucrose} \times 100}{\text{per cent. Total Solids}}$$

When sucrose is thought to be present in very small amounts, such as entrainment in condensate, its presence is indicated qualitatively by the delicate α-naphthol test.

Reducing Sugars.

In general factory terminology, reducing sugars are called "glucose." The technical difference is worthy of notice. Reducing sugars, as applied to the cane juice constituents, means unequal proportions of two separate sugars, namely glucose or dextrose and fructose or levulose. It is the more correct term because glucose and fructose seldom exist in the juice in equal proportions. The term "glucose" as applied to the cane juice constituents is therefore wholly inaccurate but must be admitted on the ground of general use only. Another term sometimes used is "invert sugar." This means equal proportion of glucose and fructose such as are obtained by the hydrolysis or inversion of sucrose. It has therefore a specific meaning only, although like "glucose" it must be admitted on the ground of general use.

The estimation of reducing sugars is necessary in order that sucrose inversion and destruction can be detected. The methods used are based on the fact that these sugars are able to precipitate copper from copper solutions by reduction (hence the name "reducing sugars") under certain specific conditions. When these conditions are laid down, it can be shown that a unit weight of copper is precipitated by a definite weight of reducing sugar. Two procedures are therefore possible : (a) a measured volume of the material is taken, and after precipitation the copper is weighed and the weight interpreted in terms of weight of reducing sugar. This weight of reducing sugar was therefore contained in

the originally measured volume. (*b*) A definite volume of a standardized copper solution is taken, and the material titrated until all the copper is precipitated. The volume required, i.e. the burette reading, then contains the reducing sugar equivalent of the weight of copper taken in the volume of the standardized solution.

A volumetric method is usually favoured in the control laboratory, that is a method based on procedure (*b*). The juice or molasses to be tested is clarified with lead acetate (not sub-acetate because this precipitates a part of one of the reducing sugars) and excess lead and calcium are removed. After filtration and making up to the required volume, the titration proceeds using methylene blue solution to indicate the end point by a disappearance of its blue colour.

Moisture.

The moisture content of certain products is necessary because of its effect on a subsequent process. For example, moisture per cent. bagasse is required because the bagasse is used as fuel. The estimation of moisture is carried out by heating the material at a temperature slightly greater than the boiling point of water. The temperature must not be such that destruction of one of the other constituents is brought about. It is necessary to ensure that all the moisture is driven off before re-weighing.

Other Determinations.

A variety of other determinations are possible in the control laboratory. The extent to which they are carried out depends on the requirements of the factory superintendent. The following may be described :—

pH.—The *pH* scale is a method of expressing the hydrogen-ion concentration of a solution (see Chapter III). It may be determined either colorimetrically, using suitable indicators, or electrometrically. The colorimetric method is simple and accurate enough for control purposes. It has been found that certain dyes or indicators show a graduation of colours which vary with H-ion concentration. The method is based, therefore, on the addition of indicator solution to the juice under test and the colour developed is matched against a standard. Since factory products are themselves coloured, compensation is necessary to eliminate

the interference. Each indicator solution is effective over a certain range of *pH* readings. Wherever possible the test should be carried out using two indicators so that a check reading is obtained.

Phosphate.—The control of the phosphate content of the juice for clarification purposes (see Chapter III) is carried out using a colorimetric method. When solutions of ammonium molybdate and stannous chloride are added to a diluted juice, an intense blue colour develops, the depth of which is proportional to the phosphate content. The colour is then matched against a standard.

Sulphur Dioxide.—Sulphur dioxide is determined by titration with iodine solution, using starch solution as indicator.

Ash.—Ash is the mineral content of the juice or molasses. It is determined either by incineration or by measuring the electrical conductivity. The temperature of incineration must not be such that any of the constituents are volatilized. Unless special treatment is given, the result indicates the total ash present. The result of the electrical conductivity test indicates the soluble ash present. The electrical conductivity test is based on the fact that factory products are able to conduct electricity. It varies with several factors other than the amount of soluble ash present, hence these factors must be kept constant. The electrical method is more rapid than the incineration method, and special equipment is made for the use of the sugar industry.

Fibre.—Fibre is defined as the insoluble or structural part of the cane. It is usually determined by calculation. In the laboratory, fibre is determined by washing a sample of cane free of juice and then drying. The difficulty is not so much in the operation as in the collection of a representative sample.

Stock-taking.

At the end of each week's or fortnight's run, the factory is stopped for 24 hours for minor repairs and maintenance work. The stop is not of long enough duration for all the syrup, massecuite, etc., to be liquidated to sugar and bagged off. Some is left in process of manufacture. In order that an accurate estimate can be made of the sugar yields and losses for the period, the amount left in stock must be measured and calculated.

The process of stock-taking may be divided into : (a) The determination of the quantity of each product on hand ; (*b*) The analysis of a representative sample of each product ; and (*c*) The calculation of the expected yield of sugar therefrom.

Determination of the Quantity of Each Product.

Each tank containing the same product is dipped, and the quantity contained therein read off from a wantage table. Dipping consists of measuring in inches from the top of the tank to the surface of the material in it. The result is called the dip, the inches out or the wantage. A wantage table is one which shows the size of the tank, its capacity in cubic feet and/or gallons and the quantity contained therein for each inch of wantage. Assume a tank is 10 ft. square by 6 ft. deep. Its capacity is $10 \times 10 \times 6 = 600$ cub. ft. which is contained in 6 ft. or 72 in. of depth. With a wantage of 6 in., $600 - \left(\frac{6 \times 600}{72}\right) = 550$ cub. ft. is read off from the table.

Sampling and Analysis.

As each tank is dipped, a sample is taken from it. The size of the sample is in relation to the amount of product in the tank. Samples of the same product are then composited for a single analysis. With two tanks, one containing 600 cub. ft. and the other 300 cub. ft. of syrup, twice the quantity of sample would be taken from the first as that taken from the second.

The analyses are carried out by standard methods.

Calculations.

The stock is tabulated under column headings of product, cubic footage, Brix and purity. Tables are available which show the pounds of material per cub. ft. for each degree Brix, hence the weight of each product in stock can be calculated. The result multiplied by the Brix and that in turn multiplied by the purity give the pounds of solids (Brix) and the pounds of sucrose (Pol.) respectively in each product. The process is carried out for syrup, molasses, massecuites, etc., separately. The total pounds of solids and the total pounds of sucrose in stock are then obtained by addition. The composite purity of all products in stock is calculated as follows :—

$$\text{Composite Purity} = \frac{\text{Total lbs. sucrose}}{\text{Total lbs. Brix}} \times 100$$

Available 96° sugar is derived from the total pounds of sucrose and the composite purity by standard methods (see Control Reports).

Since the total sucrose in stock is made up of the available sucrose and the unavailable sucrose, the latter can be calculated back to final molasses and an estimate made of the final molasses in stock.

Hence stock-taking produces two figures to be used in the control report : (*i*) Tons available 96° sugar in stock, and (*ii*) Tons final molasses in stock.

Control Reports.

A control report is a calculated statement of figures showing the average analysis of the factory products, the tons of material dealt with and the yields and losses of sucrose, etc. It is made up in a simple form each 24 hours, and in a more elaborate form each week. Since the weekly report embodies all calculations and figures used in the daily report, the former only is discussed.

Average Analysis.

The average analysis of a product may be derived by one of two methods :—

(*a*) The true average, calculated from tons weight.

(*b*) The weighted average, which is not to be confused with the arithmetical average.

The *true average* is used when the product is of basic importance to the further calculation of the report. The following may be grouped under this heading : Cane, Bagasse, Normal Juice, Mixed Juice, Filter Cake, Sugar, Final Molasses. The tons of the required constituents (e.g. sucrose) together with the weights of the product are calculated each day and entered in a suitably designed record book, so that at the end of the week the true average can be easily obtained by addition and division.

Weighted averages are used for the analysis of the Crusher Juice, Clarified Juice, Filter Juice, Syrup, Massecuites and the high grade Molasses. The average analysis of the "A" massecuites is obtained, for example, by taking into account the number struck each day.

Tons of Material.

The total tons of material is obtained by simple addition of the daily weights. In cases where the material is measured, the weight must be calculated therefrom. In the discussion on Weights and Measurements it was stated that the *Tons of Maceration water* can be obtained from the calculated tons of dilution water. The maceration water applied to the mill leaves it either in the juice or in the bagasse. That part of the maceration water which leaves the mill in the juice is known as *Dilution water*. The juice which contains the dilution water is known as *Dilute juice* or *Mixed juice*. Juice as it exists in the cane, that is without the addition of dilution water, is known as *Normal or Absolute juice*, therefore :

$$\text{Tons Mixed Juice} = \text{Tons Normal Juice} + \text{Tons Dilution Water} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Since the only difference between mixed juice and normal juice is the amount of dilution water, the tons of solids and of sucrose, etc., dissolved in each is the same. Therefore, since the Brix hydrometer is graduated on a basis of percentage by weight and its reading is an estimate of the per cent. solids by weight, the percentage by weight of dilution water added to the juice can be obtained by calculation from the Brix hydrometer readings as follows :

$$\text{Dilution Water per cent. Mixed Juice} = \frac{\text{Brix Normal Juice} - \text{Brix Mixed Juice}}{\text{Brix Normal Juice}} \times 100 \ldots . (2)$$

$$\text{Dilution Water per cent. Normal Juice} = \frac{\text{Brix Normal Juice} - \text{Brix Mixed Juice}}{\text{Brix Mixed Juice}} \times 100 \ldots . (3)$$

The tons of mixed juice is recorded and the tons of dilution water calculated therefrom.

In using the tons of dilution water to calculate the tons of maceration water, a maceration factor is used :

$$\text{Maceration Factor} = \frac{\text{Tons Dilution Water}}{\text{Tons Maceration Water}} \ldots . (4)$$

Hence, knowing the tons of dilution water, the tons of maceration water can be calculated. The maceration factor expresses the proportion of maceration water which appears as

dilution water. It is capable of wide variation, and this method of calculating tons maceration water is therefore only used if weighing machines or measuring devices are not available.

Certain other weights are calculated each day. The *tons of bagasse* is obtained by difference, using the following milling equation :

$$\text{Tons Cane} + \text{Tons Maceration Water} = \text{Tons Mixed Juice} + \text{Tons Bagasse} \quad \ldots\ldots (5)$$

A similar equation can be used for calculating the weight of sucrose and of fibre in cane :

$$\text{Tons Sucrose in Cane} = \text{Tons Sucrose in Mixed Juice} + \text{Tons Sucrose in Bagasse} \quad \ldots. (6)$$

Both entries on the right hand side of the equation are obtained from the tons of material and the sucrose percentage therein.

Fibre is defined as the insoluble structural part of the cane. Therefore all the fibre in the cane will appear in the bagasse.

$$\text{Tons Fibre in Cane} = \text{Tons Fibre in Bagasse} \quad \ldots. (7)$$

When tons of fibre is calculated, it is derived from fibre per cent. bagasse. Bagasse is composed of moisture, soluble solids in residual juice and fibre. Moisture is determined by analysis. Soluble solids in residual juice are calculated, assuming the purity of the residual juice is the same as the purity of the last roll juice. Sucrose per cent. is obtained by analysis, therefore :

$$\text{Soluble Solids per cent. Bagasse} = \frac{\text{Sucrose per cent. Bagasse}}{\text{Purity Last Roll Juice}} \times 100 \quad \ldots\ldots (8)$$

Tons soluble solids in bagasse can then be derived, and

$$\text{Tons Fibre in Bagasse} = \text{Tons Bagasse} - (\text{Tons moisture} + \text{Tons Soluble Solids}) \quad \ldots\ldots (9)$$

The tons of sucrose in mixed juice is also known as the *Tons of Indicated Sucrose.* That proportion of the indicated sucrose which is thought to be recoverable, or which is thought will not appear in final molasses, is called the *Available Sucrose.* It varies with the purity of the juice, that is, with the amount of impurities present. The tons of available sucrose can be calculated by the use of one of two formulae :

Winter's Formula.

$$\text{Tons Available Sucrose} = \text{Tons Indicated Sucrose} \times \left(1{\cdot}4 - \frac{40}{\text{Purity}}\right) \ldots\ldots (10)$$

Deerr's Formula.

$$\text{Tons Available Sucrose} = \text{Tons Indicated Sucrose} \times \left(\frac{S\,(J - M)}{J\,(S - M)}\right) \ldots\ldots\ldots (11)$$

in which S = Gravity purity of the raw sugar.
J = Gravity purity of the original material.
M = Gravity purity of the residue (molasses).

The amount of sucrose actually recovered is termed Tons Recovery Sucrose. It is derived from the weight and polarization of the sugar.

The fate of the indicated sucrose may therefore be conveniently tabulated as follows :—

Tons Indicated Sucrose =
Tons Recovery Sucrose + Tons Sucrose Lost....(12)

Tons Sucrose Lost =
Tons Sucrose in Filter Cake + Tons Sucrose in Final Molasses + Tons Sucrose in Other Losses..(13)

Tons of sucrose in filter cake and in final molasses is obtained from the weight of the material and the sucrose percentage therein.

Yields and Losses.

The yields and losses of the factory are expressed as percentages or ratios. Since the report is made up with an estimated amount of available sucrose in process, this must be added to that already bagged off as sugar to obtain the yield, then

Tons Recovery Sucrose = Tons Sucrose in Sugar +
Tons Available Sucrose in Process ..... (14)

When the yields are expressed as sugar, the tons available sucrose in process is calculated as standard 96° raw sugar by dividing by 0·96.

The recovery of sucrose takes place in two stages : (1) Expression of the juice by the mills, and (2) Recovery of sucrose from the expressed juice in the boiling-house. The yields

and losses are similarly sub-divided into : (1) Mill Extraction, and (2) Boiling-House Recovery.

Mill Extraction.

The degree of efficiency with which a given milling plant performs its work depends on the rate of grinding and the amount of maceration water used. Such factors as regularity of feed, mill openings, hydraulic pressures, etc., are considered as constant. One section of the report therefore sets out the mill data, which include tons of cane ground for the period, tons of cane ground per hour, tons of fibre ground for the period and per hour, tons of maceration water expressed as a percentage of the tons of cane and of fibre, etc. It has been stated in the discussion on milling that the rate of grinding is best estimated in terms of tons of fibre ground per hour. Similarly, the mill extraction is best expressed on the basis of fibre. Tons of normal juice extracted per cent. tons of cane ground, that is *Normal Juice per cent. Cane* or *per cent. Crushing* gives the yield of undiluted juice. The loss of undiluted juice is denoted by the *Normal Juice Lost per cent. Fibre* figure. The normal juice lost is the tons of normal juice in bagasse, which is found by calculating the tons of sucrose lost in bagasse to terms of normal juice. It is therefore an extraction figure which indicates the magnitude of a loss and, as such, is of extreme importance for the information of the engineer. It is of a more fundamental nature that the other commonly used milling figures, viz. : Tons of indicated sucrose per cent. Tons of sucrose in cane, or *Sucrose in Juice per cent. Sucrose in Cane.* This is entered on some reports as sucrose extraction, pol. extraction, or, simply, milling extraction. It does not take into account the amount of fibre, which is the absorbent, so to speak, resisting the action of the mills.

The mill extraction data may be elaborated by the inclusion of such figures as Sucrose in Juice per cent. Cane, Sucrose lost in Bagasse per cent. Cane which added together should equal Sucrose per cent. Cane, and Gallons of Normal Juice per ton of cane.

Boiling-House Recovery.

The starting point of the work of the boiling-house is the mixed juice, hence the fundamental yield figure is *Recovery*

Sucrose per cent. Indicated Sucrose. It is called the Boiling House Recovery. Available and Recovery sucrose may each be expressed as a percentage of the cane. An over-all figure giving an idea of the factory work as a whole together with the quality of the cane is the ratio *Tons of Cane per Ton of Sugar.*

The *Sucrose Balance* expresses all the major yields and losses in terms of sucrose in cane and of sucrose in juice (Indicated Sucrose). The form of tabulation used is as follows :—

	Tons of Sucrose in	
	(1) Cane	(2) Juice
(*a*) Tons recovery sucrose per cent.		
(*b*) Tons sucrose in final molasses per cent.		
(*c*) Tons sucrose in filter cake per cent.		
(*d*) Tons sucrose in undetermined losses per cent.		
(*e*) Tons sucrose in juice per cent.		
(*f*) Tons sucrose in bagasse per cent.		
(*g*) Tons sucrose in cane per cent.		

Entries (*g*)(1) and (*e*)(2) must of necessity be 100 in each case. There are no entries in (*f*)(2) or (*g*)(2). Entry (*a*)(1) is the *Overall Recovery*, (*a*)(2) is the *Boiling-House Recovery*, and (*e*)(1) the *Mill Extraction*, which has been discussed. The calculation of the balance is simple arithmetic, once the tons are obtained. Undetermined losses (*d*)(1) and (*d*)(2) are obtained by difference thus :—

$$(d)(1) = (e)(1) - [(a)(1) + (b)(1) + (c)(1)]$$

Similarly for (*d*)(2).

The intelligent interpretation of a control report depends not only on knowing how the figures are derived and their significance, but a knowledge is also required of the factors which influence them. It is for this reason that no attempt has been made in giving maximum, minimum and average results. The work of a factory cannot be assessed by inspection of the control reports. Local conditions, equipment capacities, etc., must be taken into account, and their individual influences given the correct bias. This is purely a matter of experience and is, therefore, best omitted from discussion in a volume of this nature.

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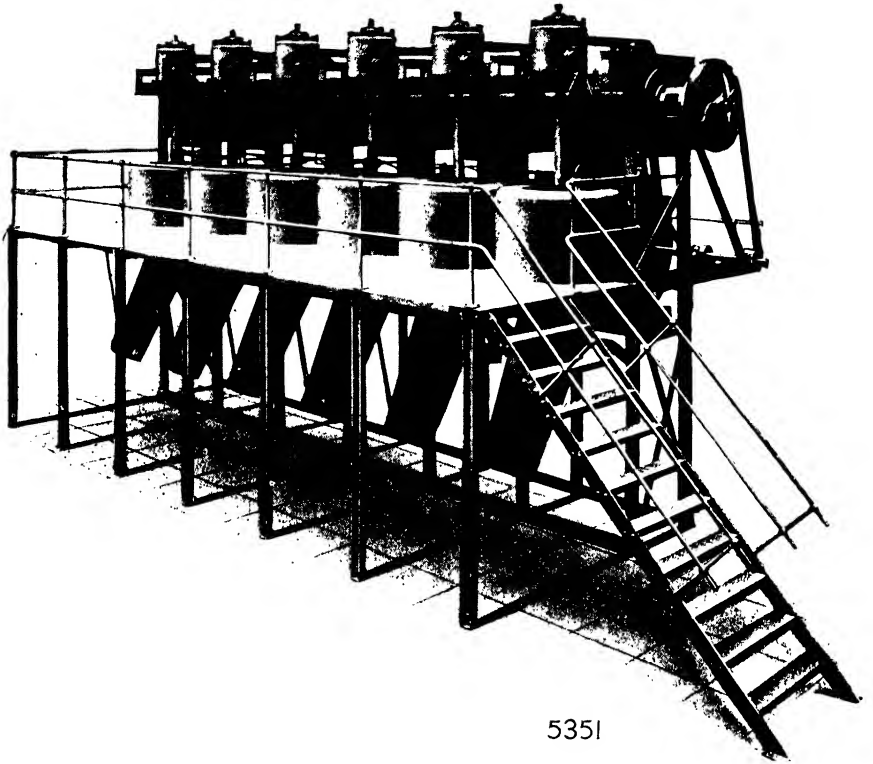

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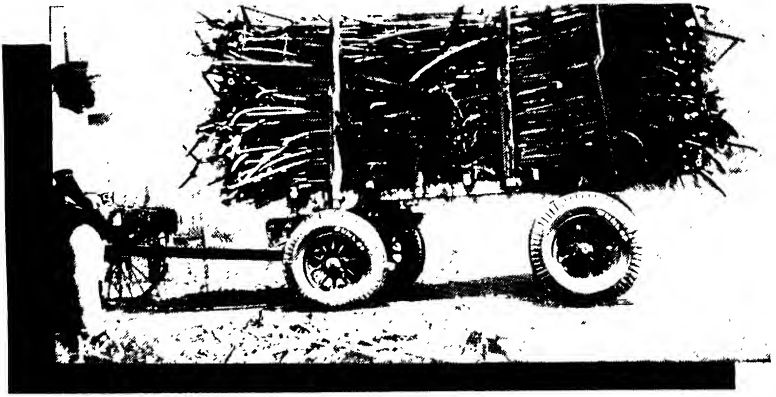

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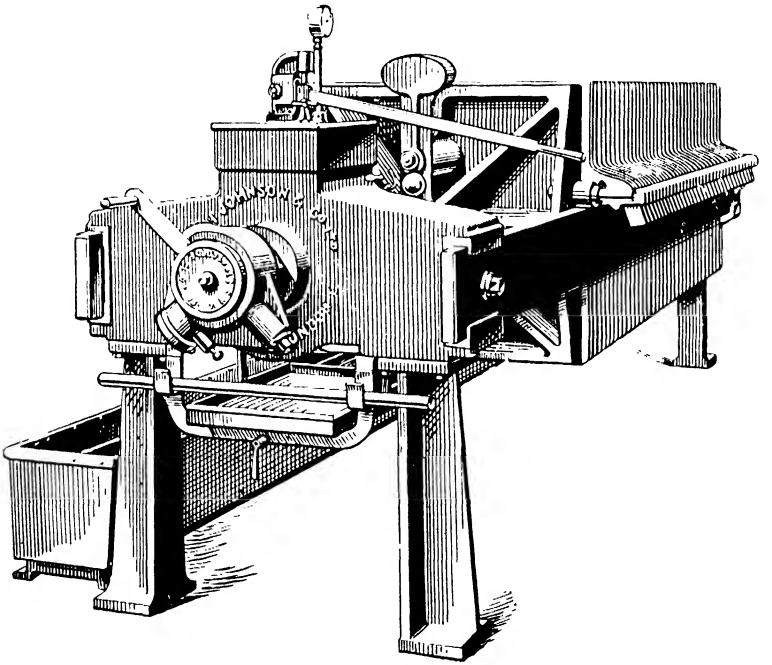

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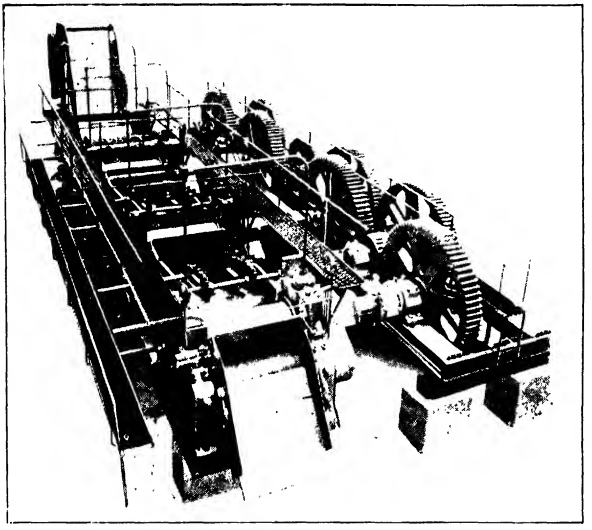

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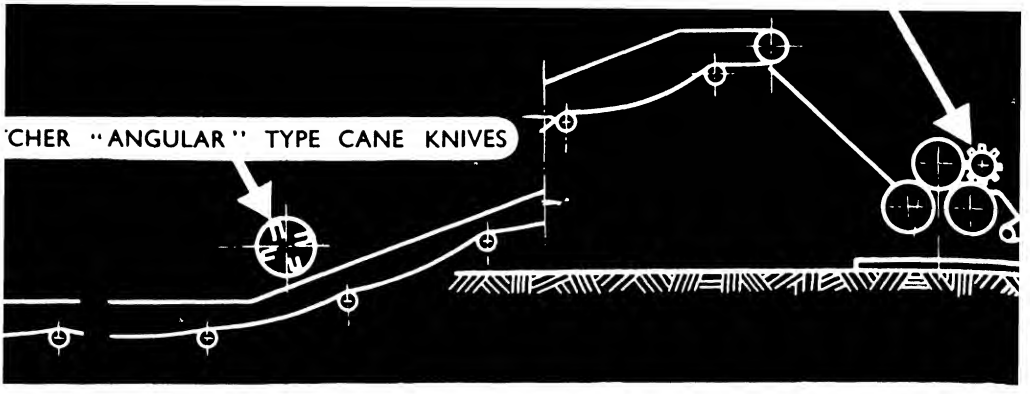

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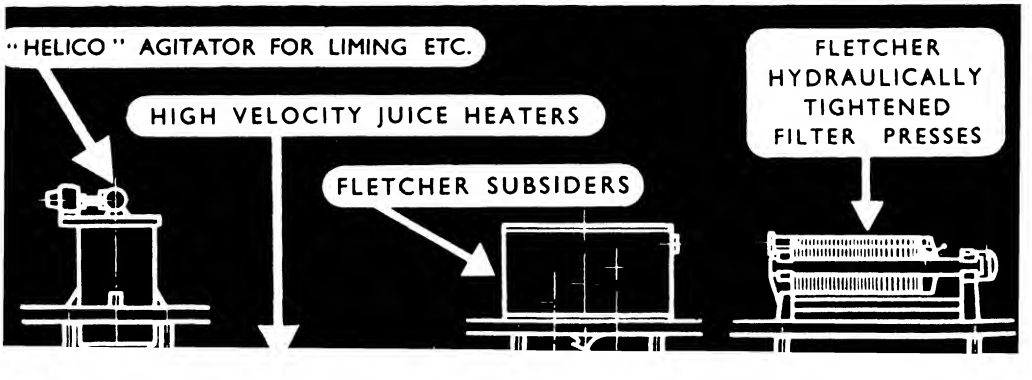

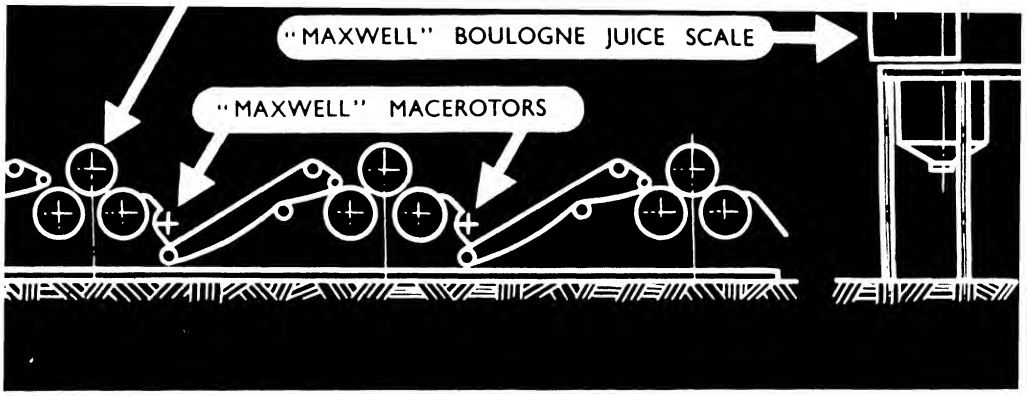

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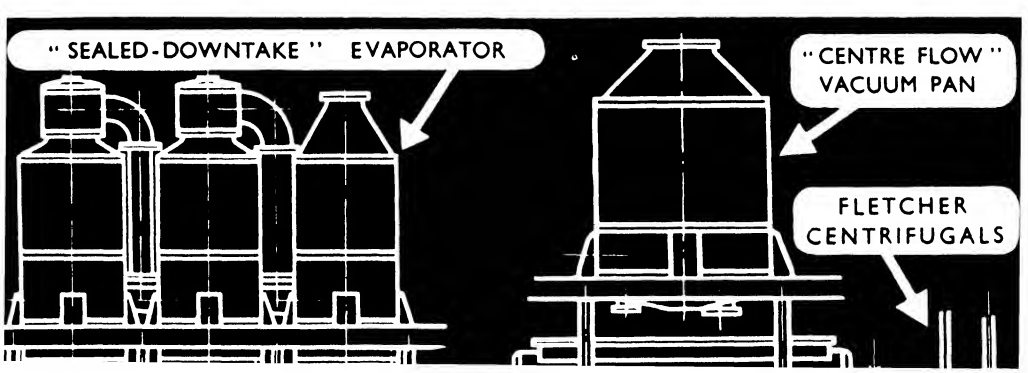

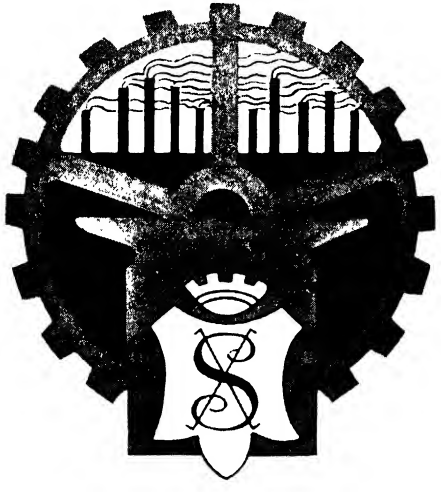

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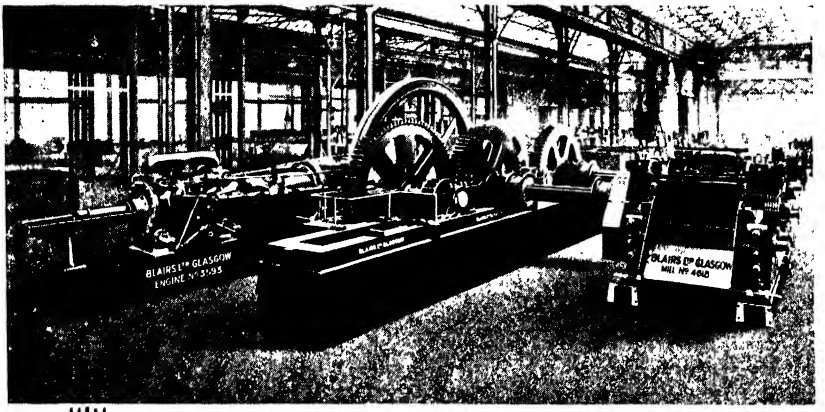

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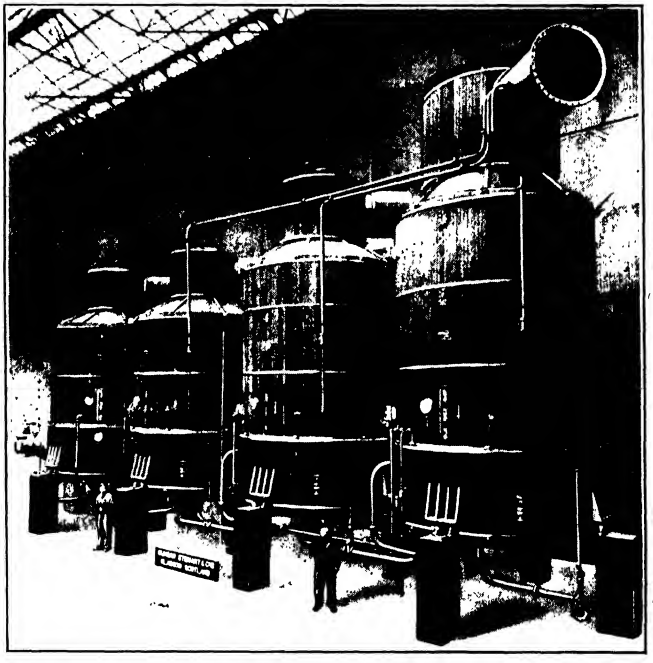

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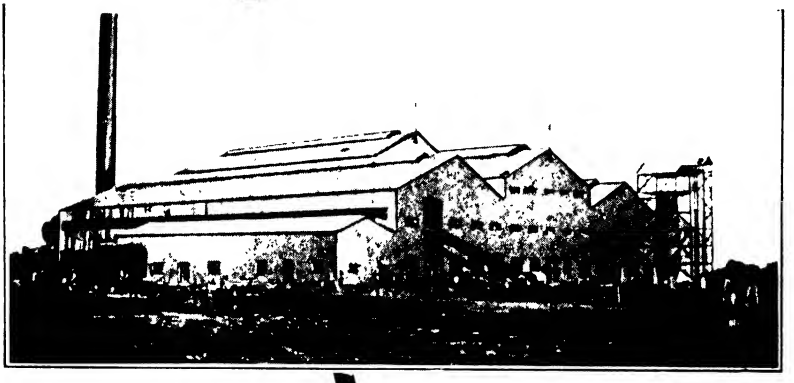

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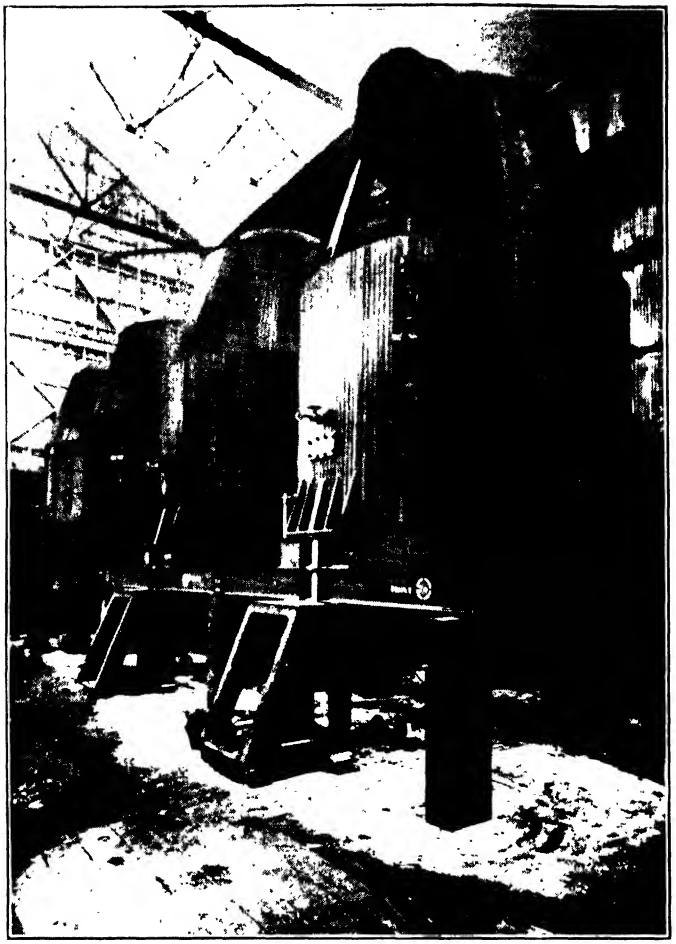

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